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Fuel Quality/Processing Study

Volume II: Appendix—Task I Literature Survey

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J. B. O'Hara, A. Bela, N. E. Jentz, H. W. Klumpe,
R. E. Kessler, H. T. Kotzot, and B. I. Loran
The Ralph M. Parsons Company

April 1981

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-183

for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Coal Utilization

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The Ralph M. Parsons Company
100 W. Walnut Street
Pasadena, California 91124

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TABLE OF CONTENTS

SECTION 1	INTRODUCTION AND OBSERVATIONS	1-1
SECTION 2	CRUDE SYNFUELS PRODUCTION, PROPERTIES AND ECONOMICS	2-1
SECTION 3	REFINED SYNFUELS PRODUCTION, PROPERTIES AND ECONOMICS	3-1
SECTION 4	GAS TURBINE FUEL CRITERIA	4-1
SECTION 5	ON-SITE FUEL PRETREATMENT	5-1
SECTION 6	FUEL STORAGE AND BLENDING	6-1
SECTION 7	EMISSION SOURCES AND CONTROLS	7-1
APPENDIX A	LITERATURE SEARCH DOCUMENT LIST AND ABSTRACTS	A-1
APPENDIX B	SUPPLEMENTARY SYNFUEL PROPERTY DATA	B-1

SECTION 1

INTRODUCTION AND OBSERVATIONS

This report presents the results of the Task I, Literature Survey, portion of the Fuel Quality/Processing Study project. The objective of the total study is to provide a data base that can be used to establish an intelligent trade-off between advanced gas turbine technology and liquid fuel quality. The objective of Task I is to survey existing literature to define the properties and characteristic of near-future (1985-2000 time period) petroleum and synfuels, synfuels processes using coal or oil shale, fuel additives, on-site treatment processes, and exhaust gas clean up processes.

Work on this project is being performed by The Ralph M. Parsons Company for NASA-Lewis Research Center under Contract DEN3-183.

Task I - Literature Survey is one of six tasks and serves as a basis for performance of the remaining tasks. In Task I, a literature search was conducted. This was accomplished by acquiring and summarizing sufficient information to define fuel quality, fuel treatment costs and process efficiencies.

The procedure used and method of presentation are discussed below.

1.1 LITERATURE SEARCH PROCEDURE

This activity was begun with the assembly of information from Parsons' files and from contacts in the development and commercial fields. A further more extensive literature search was carried out by using the Energy Data Base (EDB) and the American Petroleum Institute (API) Data Base. These are part of the DOE/RECON system.

The DOE/RECON search consisted of matching fuel related key words, such as coal liquids and Paraho process with physical/chemical property, production technology, economics and environmental related key words.

Approximately 6000 references and abstracts were obtained from the EDB search. These were reviewed and the especially pertinent documents, approximately 300, were acquired in the form of paper copy or microfiche.

A classification system consisting of six major categories, three sequential digits and five subcategories was developed for use in filing and retrieving the documents. Appendix A of the report contains the classification number list with abstracts of the document inventory acquired and used in the performance of Task I. The document numbers in the list are used as the reference identification for many of the tables within the report.

1.2 FUEL CHEMICAL/PHYSICAL PROPERTIES

A "Fuel Properties" form was developed for listing information pertinent to gas turbine liquid fuel properties specifications. Fuel properties data for liquid fuels from selected synfuel processes, deemed to be successful candidates for near future commercial plants were tabulated on the forms. The processes selected consisted of H-Coal, SRC-II and Exxon Donor Solvent (EDS) coal liquefaction processes plus Paraho and Tosco shale oil processes.

Fuel properties analyses for crude and distillate syncrude process products are contained in Section 2. Analyses representing synthetic fuels given refinery treatments, mostly bench scale hydrotreating, are contained in Section 3. A sizable actual commercial run through a mid-west refinery was made on Paraho shale oil. An attempt was made to select properties analyses on most recently produced liquid fuels for these sections.

Property analyses tabulations were made for over sixty fuel samples. These represent an inventory of analyses useful for comparative purposes. These are presented at the end of this report as Appendix B.

1.3 GAS TURBINE FUELS CRITERIA AND ON-SITE TREATMENT

Section 4 discusses gas turbine fuel specifications based on petroleum source fuels as developed by the major gas turbine manufacturers. The advent of synthetic fuels and relation to existing and future gas turbine design are discussed.

Section 5 presents the on-site gas turbine fuel treatments applicable to petroleum base fuels impurities content in order to prevent adverse contaminant effects. The relation to synthetic liquid fuels is also discussed.

1.4 STATIONARY GAS TURBINE EMISSIONS

Section 7 relates the environmental aspects of gas turbine fuel usage and combustion performance. Certain of the synthetic liquid fuels, as produced, are appreciably higher in nitrogen and some substantially lower in hydrogen content than comparable petroleum based fuels. These pose NO_x and smoke emission problems.

1.5 GENERAL OBSERVATIONS

The literature search has resulted in what should be considered "preliminary" observations which later may be substantiated or revised during the performance of project tasks.

It appears that the near future stationary industrial gas turbine fuel market will require that some of the synthetic fuels be refined to the point that they will resemble the petroleum based fuels. Guidance regarding the preferred trade-off of fuel quality and cost will be developed in later project tasks.

SECTION 2
CRUDE SYNFUELS PRODUCTION
PROPERTIES AND ECONOMICS

Liquid synfuels produced from coal and oil shale have some properties in common with petroleum based fuels and also some differences. Changes in production procedures, refining, storage and methods of feeding gas turbine combustors relative to historical procedures used with petroleum source gas turbine fuels will be required. Likewise, emission compositions will also differ; in many cases emissions can be expected to be more objectionable and require treatments not heretofore necessary.

This section summarizes production procedures, energy efficiencies, estimated economics for coal and oil shale based synfuels. It also summarizes physical and chemical properties of the crude synfuels, which in turn would represent feedstocks for refining and pretreatment steps prior to uses as turbine fuels. Technologies included in this area are:

• Coal Derived Synthetic Fuels

- (1) H-Coal
- (2) SRC II (Solvent Refined Coal)
- (3) Exxon Donor Solvent

• Shale Oil Fuels

- (4) Paraho
- (5) Tosco II

Process information extracts of these processes follow.

2.1 H-COAL PROCESS

Process Type:	Hydroliquefaction, Direct Catalytic
Main Products:	Naphtha and wide boiling range low-sulfur fuel oil, or synthetic crude oil.
Development Status:	Pilot Plant in Startup Stage
Process Developer:	Hydrocarbon Research, Inc. (HRI), A division of Dynalectron Corporation, McLean, Virginia
Process Sponsors:	(1) Continental Oil Co. (2) Mobil Oil Company

- (3) Ashland Oil
- (4) Standard Oil of Indiana (Amoco)
- (5) Electric Power Research Institute (EPRI)
- (6) Department of Energy (DOE)

2.1.1 PROCESS DESCRIPTION^{2,3}

The H-Coal process contains three major process operations.

- (1) Liquefaction
- (2) Separation (solvent recovery/removal of insoluble solids).
- (3) Hydrogen Manufacture

The integration of the units is depicted in the H-Coal block flow diagram, Figure 2-1.

A simplified flowsheet of the H-Coal PDU is shown in Figure 2-2.

In the liquefaction unit, crushed coal is slurried with recycle solvent, and the coal slurry then mixed with plant makeup hydrogen. The coal slurry hydrogen mix is preheated in a co-current radiant type fired heater and fed to the reactor. Recycle hydrogen is also preheated and fed to the reactor. The coal slurry and hydrogen flow upward through an expanded bed of hydrogenation catalyst. Internal and/or external liquid recycle may be used to maintain the catalyst in an ebullated state. Two reactors in series may be required for coals of low rank.

The reactor product liquid and coal residue are withdrawn as a slurry and reduced in pressure by means of a high-pressure drop control valve. Flash gases are separated and sent to an atmospheric distillation unit. Flash liquid is sent to a vacuum distillation unit for recovery of solvent and syn-crude. For low-sulfur fuel oil production, solids are removed from the liquid stream prior to vacuum distillation.

A proportion of the flash liquid is clarified by hydroclones and recycled to the reactors.

Hydrogen-rich gas is withdrawn from the reactor and cooled at reactor pressure to remove heavy hydrocarbons and water, then scrubbed to recover

light hydrocarbons. A proportion of the scrubbed gas is purged from the process and used as fuel and for hydrogen manufacture. The remainder is recycled to the reactor. Separated hydrocarbons are fed to the atmospheric distillation unit.

Recovered solvent from the distillation units is slurried with fresh coal to repeat the cycle. Heavy bottoms and coal residue from the vacuum unit go to a gasifier for hydrogen production.

Reactor residuum content:

It has been found that the concentration of residuum in the reaction zone has a significant effect on the conversion of coal to distillate products. Increasing the residuum content of the reactor slurry from 21.1 to 33.0 wt% resulted in a 30% reduction in required reactor residence time, and increased the C₄-975°F distillate yield by 11%.

Coals Processed:

Lignite, Brown Coal, sub-bituminous, bituminous C, high volatile bituminous.

2.1.2 INTENDED PRODUCT USE/MARKET

HRI has prepared a process design for a hydrogen refinery to upgrade the coal liquids to gasoline and furnace oil.⁴ Naphtha, middle distillates, and heavy gas oil are hydrotreated to reduce sulfur and nitrogen levels. Middle distillates are hydrocracked to light and heavy naphtha. Crude naphthas and hydrocrackates are upgraded by catalytic reforming to high octane gasoline blending stocks.

Vacuum bottoms from the H-Coal process are coked to yield additional heavy gas oil and a coal residue (Char-Ash-Coke).

23,500 tons per day (TPD) of Illinois No. 6 coal are converted to 50,000 barrels per stream day (BPSD) of liquid fuels.

2.1.3 PROCESS EFFICIENCY² (Illinois No. 6 coal feed)

	<u>Synthetic Crude</u>	<u>Low Sulfur Fuel Oil</u>
A. <u>Thermal efficiency</u>		
Product only, %	74.7	62.6
Overall, including net utilities, %	62.7	56.0
B. <u>Utilities, per ton dry coal</u>		
Power, kWh	201	157
Fuel (coal), MM Btu	0.96	0.
Raw water, gal.	661	501
C. <u>Hydrogen consumption</u>		
wt% MAF coal liquefied	5.44	3.57
SCF/bbl net oil	6210	4354
D. <u>Catalyst</u> ³		
Average life of cobalt molybdenum catalyst for low sulfur fuel, lb coal/lb catalyst	N/A	1000

2.1.4 UNIQUE FEATURES OF PROCESS

Main features of the process are:

Coal slurry hydrogenation in a catalytic ebullating bed reactor, recycle of residuum to the reactor, product oil used to slurry coal, and addition of molecular hydrogen to reactor.

2.1.5 PROCESS STATUS

A. Development Status

A 3-TPD continuous process development unit began operation
1971.

Design for a nominal 200-600-TPD pilot plant began September 1974 which was constructed at Catlettsburg, Kentucky. Startup of major process sections is presently underway with operation by Ashland Synthetic Fuels, Inc., a wholly owned subsidiary of Ashland Oil, Inc.

B. HRI Patents

U.S.-3,519,553
U.S.-3,519,555
U.S.-3,540,995
U.S.-3,617,474
U.S.-3,700,584

C. Location of Development Work

PDU located at HRI laboratory, Trenton, New Jersey. Pilot scale plant located adjacent to the Ashland Oil Refinery at Catlettsburg, Kentucky.

D. History

The H-Coal process is a related application of the ebullated bed H-Oil process, developed by HRI and Cities Service Oil Company to convert heavy petroleum oil residues into lighter fractions. First H-Oil commercial installation put into operation in 1963.

Early development of the H-Coal process began mid 1960s in 25 lb per day bench-scale units sponsored by the Office of Coal Research (OCR) until September 1967. From 1968 to 1970 the program was supported by ARCO, and from 1971 to 1972 by a consortium of six companies. A 3-TPD PDU began operation 1971. From 1973 to 1974 the program was supported by a consortium of four companies. Since 1974 four oil companies, EPRI, and DOE have sponsored the program.

Approximately 1200 days of operation were obtained in the bench-scale units, and 147 days in the PDU.

PDU tests since 1974 have been directed towards confirming the design basis for 600-TPD pilot plant. Liquid/solid separation schemes are also currently being studied.

The pilot plant was designed to process:

- (1) 633 TPD coal to 1920 BPSD 0.7 wt% S fuel oil or,
- (2) 210 TPD coal to 740 BPSD synthetic crude.

2.1.6 PRODUCTS

The major liquid products consist of naphtha, middle distillate, 400°F-plus distillates and residual oils. The properties of these products are tabulated in Tables 2-1, 2-2, 2-3 and 2-4. Coal source of the liquids described in these tables was Illinois No. 6, Burning Star Mine.⁵

H-Coal naphtha is high in oxygen and basic nitrogen, due to the presence of phenols, anilines and pyridines. Neither the naphtha nor the fuel oil meets existing gasoline or distillate fuel oil specifications, due in part to relatively high levels of sulfur, nitrogen, and oxygen. Sulfur and nitrogen also interfere with standard refining processes that are used to make gasoline, such as reforming, and would need to be removed by, for example, hydrotreatment. The naphtha contains predominantly cyclic compounds and, upon refining, should yield high octane gasoline and hydrogen, primarily due to dehydrogenation of naphthenes.

2.2 SRC PROCESS

Process Type: Hydroliquefaction

Main Products: SRC
 LPG - C₃, C₄
 Light Distillate Oils
 Heavy Distillate Oils
 SRC

Development Status: Pilot Plant Demonstration Plant Design

Process Developers:⁶

- (1) Pittsburg and Midway Coal Mining Company
 (PAMCO), a subsidiary of Gulf Oil Co.:

PAMCO operates a nominal 48-TPD pilot plant located at Fort Lewis, Washington and a bench scale PDU located at Merriam, Kansas.

- (2) Catalytic, Inc. (Southern Company Services, Manager):

Catalytic operates a 6-TPD SRC I pilot plant located at Wilsonville, Alabama.

- (3) Colorado School of Mines (CSM):

CSM operates laboratory-scale units at Golden, Colorado.

Process Sponsors:

- (1) DOE sponsors development work performed by PAMCO and CSM.
- (2) DOE and EPRI cosponsor SRC I development work performed by Catalytic, Inc.

2.1.1 PROCESS DESCRIPTION

Figure 2-3 shows the SRC II process. Dried and pulverized coal is fed to the slurry mixing vessel, where it is mixed with a slurry recycle stream. The slurry recycle is a flashed stream from the vapor-liquid separation section containing dissolved and undissolved coal, including the coal ash. The mineral contents of the coal act as a catalyst in the dissolving, hydrocracking, and hydrogenation reactions; hence, for the same residence times, the degree of reaction, as measured by the hydrogen consumption, is substantially increased in the SRC II mode, or slurry recycle mode, over the SRC I mode. The entire slurry is pumped from the mixing vessel and the recycle plus make-up hydrogen is injected into the stream ahead of the slurry heater. The entire mixture is heated to about 700°F in the slurry heater and then enters the dissolver.

Reaction heat increases the temperature of the reactants to over 800°F. The reactor effluent is then let down in pressure and cooled in several flash separations in the vapor-liquid separation section. The gases separated are sent to an acid-gas removal section for CO₂ and H₂S removal. The gases then are cryogenically separated into hydrogen, methane and LPG streams. The hydrogen is purified and recycled. The methane is purified by methanation and dehydration to pipeline gas. Part of the slurry liquid stream is recycled to the slurry mixing tank; the balance fed to a vacuum tower. Here fuel oil is distilled and a mineral residue slurry discharge from the bottom. The light liquid stream from the gas-liquid separator is separated into naphtha and fuel oil fractions.

The mineral residue slurry is sent to an oxygen blown gasifier where synthesis gas is generated, then shifted and purified to produce the make-up hydrogen required for the dissolver. The excess synthesis gas is routed through an acid gas removal unit and is used as plant fuel, sulfur being recovered from the separated hydrogen sulfide

Hence, this operation would produce only gases and liquid:

SNG, LPG:	C_3, C_4
Light Oils:	IBP - 400°F
Middle Distillate Fuel:	400 - 550 °F
Heavy Distillate Fuel:	550 - 950°F

2.2.2 OPERATING CONDITIONS

- A. Temperature: 700 - 900°F
- B. Pressure: 1,000 - 2,500 psi
- C. Coal Residence Time: 15 - 150 min.
- D. Coal Space Velocity
(defined to be equal to lb/h coal feed per ft³ reactor): 15 - 100 lb/h/ft³
- E. Conversion (MAF conversion is defined to be equal to $\frac{100 - \text{lb unreacted organic solids}}{100 \text{ lb MAF coal feed}} \times 100\%$): 80 - 95%
- F. Coals processed: Kentucky No. 9 and No. 14 Coals
Illinois No. 6 Coal
Pittsburgh No. 8 Coal
Wyodak, Wyoming Coal
- G. Catalyst: None*
- H. Vehicle: Hydrogen (for hydrogenation)
Solvent (for coal dissolving)
Solvent (as H₂ donor solvent)
Coal ash (as pseudocatalyst)

* Although no catalyst is used, it is believed that the minerals in coal (and the slurry recycle if used) have a pseudocatalytic effect; slurry recycle, or SRC II, increases hydrogenation of the coal presumably due to this pseudocatalytic effect.

I. Reaction variables: Reaction temperature
 (affecting the MAF Reaction pressure (H_2 partial pressure)
 conversion and/or Unfiltered-slurry-recycle to coal ratio
 hydrogen consumption) Filtered-solvent-recycle to coal ratio
 Reactor residence time
 Type of coal

J. Recycle Wt Ratios:

Slurry to Coal	2:1
Solvent to Coal	1:1

K. Yields (wt% MF Illinois No. 6 Coal Feed):

C_1	4.7
C_2	2.93
C_3	3.87
C_4	1.88
CO	-
CO ₂	1.06
H ₂ S	2.65
NH ₃	0.24
H ₂ O	2.67
Light Oil (IBP - 400°F)	6.50
Wash Solvent (400 - 500°F)	7.34
Process Solvent (500 - 850°F)	15.25 (500 - 950°F)
SRC 850 °F+	36.70
Ash	12.13
Unreacted Coal	<u>6.78</u>
Total (including H ₂ consumption)	104.7

L. Characteristics (typical):

1) Light Oil Composition (wt%)

C	78.92
H	14.31
N	0.31
S	0.31
O	6.15
Ash	-
	100.00

Gross Heating Value
(Btu/lb) 19,890

Boiling Range 400°F

2) Wash Solvent Composition (wt%)

C	81.61
H	10.90
N	0.68
S	0.27
O	6.54
Ash	-
	100.00

Gross Heating Value
(Btu/lb) 18,134

Boiling Range: 400 - 500°F

3) Process Solvent Composition (wt%)

C	83.41
H	9.18
N	1.11
S	0.33

O	5.97
Ash	-
	<u>100.00</u>
Gross Heating Value (Btu/lb)	17,376
Boiling Range	500 - 950°F
4) SRC Composition (wt%)	
C	86.70
H	7.41
N	1.61
S	0.44
O	3.84
Ash	-
	<u>100.00</u>
Fusion Point:	300°F ⁽⁸⁾
Boiling Range:	950°F+
Gross Heating Value (Btu/lb):	16,926

2.2.3 INTENDED PRODUCT USE/MARKET

A. SNG and LPG:

The hydrocarbon gases produced by the SRC II process constitute a high-Btu fuel gas. After recovery and purification, the SNG may be used as plant fuel gas and/or sold as pipeline quality gas. LPGs are also marketable products available from the SRC II process.

B. Naphtha and Middle Distillate Oil:

The naphtha or middle distillate oil product must be hydro-treated for heteroatom (N, S, and O) removal; then it is valuable as a good reformer feedstock, as a precursor to lead-free gasoline due to its high aromatic and naphthenes content.

C. Heavy Distillate Fuel Oil:

Heavy distillate fuel oil may be marketable to the utilities industry as a No. 6 residual fuel oil and can be made suitable as a gas turbine fuel.

Tables 2-5 and 2-6 present the properties of the syncrude fractions which are likely candidates as gas turbine fuels.

2.2.3 PROCESS EFFICIENCY

A. Thermal Efficiency:

- Oil/Gas Conceptual Commercial Plant⁹: 77.6%
- Utilities (including slurring, dissolving, and filtration only)⁸

Basis:	1 ton moisture-free coal
Fuel Gas (internal consumption:	780 M Btu
Cooling Water:	250 gal
Power:	66 kWh
High-pressure Steam:	310 lb generated
Low-pressure Steam:	80 lb generated
Hydrogen Consumption:	4.7 lb per 100 lb dry coal

2.2.5 UNIQUE FEATURES OF PROCESS

- (1) The process can produce a liquid or solid boiler fuel, depending on the amount of hydrogenation and the amount of lighter organic liquids (wash and process solvents) included in the boiler fuel blend.
- (2) The process can use synthesis gas ($\text{CO} + \text{H}_2$) or hydrogen for liquefaction; also the solvent is believed to act as a donor of hydrogen to the coal.
- (3) The reaction is a three-phase reaction: gas, liquid, and solids.

- (4) Although the process is noncatalytic, it is believed that the minerals in the ash act as a pseudocatalyst in promoting hydrogenation.
- (5) There is an optimal band of operating temperatures for good conversion (90%) of MAF coal to gas, liquids, and SRC. Below this band, conversion is limited by the Arrhenius reaction rate; above the band, thermal cracking and coke formation limit conversion.

2.2.6 PROCESS STATUS

A. Development Status

Two pilot plants are operational. Also, there have been several conceptual designs of commercial-size coal liquefaction plants using the SRC I and II processes. At the present time, DOE has defined funding requirements and is making plans for the design, construction, and operation of a demonstration plant.¹⁰

The process has been patented (U.S. Patent 3,341,447).¹¹

B. History

Solvent refining of coal dates back to the Pott-Broche process developed in Germany in the 1920s. The process was utilized by Germany in World War II for the production of a raw material for carbon electrodes for aluminum plants. In the 1950s, R&D work on a modified Pott-Broche process was performed by the Spencer Chemical Company. In 1962, the U.S. Office of Coal Research (OCR) awarded a research contract to Spencer for technical evaluation of the SRC process. The process was demonstrated in a 50-lb/h, continuous-flow PDU in Merriam, Kansas. At the time, Gulf Oil Corporation acquired Spencer and reassigned the SRC project to The Pittsburgh and Midway Coal Mining Company. In 1966, OCR awarded PAMCO a contract for a study of the commercial feasibility of the process to include design, construction, and operation of a 50-TPD pilot plant. Stearns-Roger Corporation completed design of the plant in 1969 and after

a delay due to lack of funds, detailed engineering and construction were awarded to Rust Engineering Company. The plant started up in late 1974 and has been in operation since then along with the PDU in Merriam, Kansas. A 6-TPD SRC pilot plant was built in 1974 by Catalytic, Inc., which operates it now under the sponsorship of DOE and EPRI. southern Company Services, Inc. serves as project manager.

There are many supporting studies for the SRC process, including product testing, product upgrading, process evaluations, and mechanical equipment testing.¹

2.3 EXXON DONOR SOLVENT (EDS) PROCESS

Process Type:	Hydroliquefaction, Indirect (Donor Solvent)
Main Products:	Naphtha and wide boiling range low-sulfur fuel oil
Development Status:	Pilot plant.
Process Developer:	Exxon Research and Engineering Company, Florham Park, New Jersey
Process Sponsors:	Exxon Corp. Electric Power Research Institute (EPRI)

2.3.1 PROCESS DESCRIPTION¹²

The EDS process contains four major process unit operations:

- (1) Liquefaction
- (2) Separation (solvent recovery)
- (3) Solvent Hydrogenation
- (4) Hydrogen Manufacture

The integration of these units is depicted in the EDS block flow diagram (Figure 2-4). A simplified flowsheet of the EDS liquefaction and separation units is shown in Figure 2-5.

In the liquefaction unit, crushed coal is slurried with recycle solvent and preheated to reaction temperature. The hot coal slurry is mixed with preheated hydrogen recycle and the combined stream fed to the liquefaction reactor.

The product from the liquefaction reactor is separated into gas and liquid/residue streams in the hot high-pressure separator. The gas stream is cooled to remove heavy hydrocarbons and water, and then scrubbed to remove acid gases.

The liquid/residue stream is reduced in pressure and flash gases separated. The flash-gas is processed to recover heavy hydrocarbons. The slurry product is sent to the separation unit where gas, naphtha, recycle solvent, distillate, and heavy bottoms (containing all the solid residue from the liquefaction, and some very high boiling hydrocarbons are separated by distillation. Liquids boiling up to 1000°F are recovered from the product slurry by vacuum distillation, and then further fractionated into light vacuum gas oil, boiling up to 700°F, and a heavy vacuum gas oil product. The light vacuum gas oil is combined with other recovered liquid hydrocarbon streams and this material is fed to the hydrotreating system.

The liquid product is fractionated to remove lighter and heavier boiling range components from the recovered solvent. The excess solvent is removed from the system as a product.

In an earlier alternative version of this process only recycled solvent is hydrotreated.¹³

Fixed-bed catalytic reactors are used for solvent hydrogenation. The reactors are provided with quench hydrogen for temperature control. High pressure hydrogen-rich gas is cooled to remove heavy hydrocarbons and water, and then scrubbed to remove acid gases. In an earlier alternative version of the process, solvent was hydrogenated with gas from the HT/HP separator, and liquid feed was used for quench temperature control.¹⁴

Scrubbed gases from the hydrotreater and liquefaction reactors are compressed and recycled to the liquefaction unit.

Hydrotreated liquid is reduced in pressure and flash gases separated. The flash-gas is processed to recover heavy hydrocarbons. Flashed liquid is fractionated, as described above, for solvent recovery.

Recovered solvent is slurried with fresh coal to repeat the cycle. Heavy bottoms and solid residue go to a gasifier for hydrogen production.

Gas generated from the process is used as fuel and for hydrogen manufacture.

2.3.2 OPERATING CONDITIONS

A. Liquefaction

	Coal Processed	
	Bituminous/ Sub-bituminous ¹²	Illinois No. 6 ¹⁴
Pressure, atm	100-175	123
Temperature, °F	700-900	825
Solvent/Coal, wt/wt	1.2 - 2.6	0.5
H ₂ /Coal, wt% MAF coal	N/A	5.75
SCF/lb coal	N/A	8.2
Residence Time, min	N/A	36
Conversions		
H ₂ , wt% MAF coal	N/A	1.74
H ₂ , SCF/bbl oil	N/A	630
Catalyst	none	none

B. Solvent Hydrogenation

Pressure, atm	80 - 210	122
Temperature, °F	500 - 840	725
H ₂ /Oil, SCF/bbl	N/A	4730
Space Velocity, wt/hr/wt	0.2 - 4.0	4.0
Conversion		
H ₂ , wt% MAF coal	N/A	1.30
H ₂ , SCF/bbl oil	N/A	630

Catalyst

commercial multi-
metallic catalystscobalt molybdate
on silica-alumina

Reaction Variables:

A wide range of process conditions have been studied by Exxon. Coal conversion has been correlated with a solvent quality index.¹² The quality index varies with the degree of solvent hydrogenation. Details of the index are proprietary. These correlations show that the addition of molecular hydrogen to the liquefaction reactor significantly reduces the solvent quality requirement.

Coal Processed: Bituminous and sub-bituminous coals.

2.2.4 PRODUCTS¹²

	Heavy Naphtha*		392° + Fuel Oil	
	Raw Liquid	Hydrotreated Liquid	Raw Liquid	Hydrotreated Liquid
Nominal Boiling Range, °F	158/392	158/392	392/1004	392/1004
Distillation, °F:				
10 wt%	223	198	477	462
50 wt%	356	315	694	657
90 wt%	390	360	811	774
Density (g/cm ³):	0.87	0.80	1.08	1.01
Elemental Analysis, wt%:				
C	85.60	86.80	89.40	90.80
H	10.90	12.90	7.70	8.60
O	2.82	0.23	1.83	0.32
N	0.21	0.06	0.66	0.24
S	0.47	0.005	0.41	0.04
Higher Heating Value, Btu/lb:	18315	19304	17110	18900

* Excludes C₆/158°F naphtha cut

2.3.5 INTENDED PRODUCT USE/MARKETS

(1) Naphtha

The ($C_6 - 158^{\circ}F$) and ($158 - 392^{\circ}F$) fractions are identified as potentially valuable naphtha blending stocks.

(2) Low-Sulfur Fuel Oil (LSFO)

The LSFO consists of a mid-distillate and a heavy gas oil. Economic studies have shown that these cuts are potentially valuable.

(3) Chemicals

Specialty product chemicals can be separated from the naphtha and LSFO.

(4) Table 2-7 and 2-8 present recent product characteristics for gas turbine fuel candidate fractions.

2.3.6 PROCESS EFFICIENCY

A. Thermal Efficiency¹²

Product only, %: 80 - 90

Overall, including net utilities, %: 65 - 75

B. Hydrogen Consumption¹⁴

wt% MAF coal to liquefaction unit: 3.04

wt% liquid yield: 6.2 - 7.3

C. Catalyst: ¹⁴

Cobalt molybdate catalyst life (between regenerations) - over one year.

2.3.7 UNIQUE FEATURES OF PROCESS

Main features of the process are: Noncatalytic proprietary liquefaction reactor, production of the donor solvent in a fixed-bed catalytic hydrogenation reactor, addition of molecular hydrogen to the liquefaction reactor, and vacuum distillation to separate unconverted coal, ash, and liquids boiling over 1000°F from the reaction product.

2.3.8 PROCESS STATUS

A. Development Status:

One-ton-per-day continuous pilot plant constructed July 1965 and put in productive operation. Basic design specifications for a 250-TPD pilot plant were made from this unit.

B. Exxon Patents:

U.S. - 3,645,885

U.S. - 3,726,784

C. Location of Development Work:

Construction on the large scale pilot plant located adjacent to Exxon's Baytown, Texas, refinery was completed early in 1980 with operation projected to begin in April or May of 1980

2.4 PARAHO SHALE OIL PROCESS

Process Type: Pyrolysis via Partial Oxidation

Main Products: Fuel Oil, High-Btu gas

Development Status: Pilot Plant
Process Developer: Development Engineering, Inc.
Process Sponsor: Paraho Development Corporation

2.4.1 PROCESS DESCRIPTION¹⁵

The vertical downflow retort constitutes the major operating equipment for this process. This is diagrammed in figure 2-6. The retort is similar to a vertical lime-burning kiln. Crushed oil shale is continually charged at the top of the unit and mechanically spread to provide a uniform bed. The crushed oil shale flows downward countercurrently to hot vapor and gas upflow fueled by three stages of gas/air mixtures, the major heat source being combustion of coke in the spent shale.

Shale oil vapor is collected and flows to the oil recovery unit. Spent shale is discharged out the bottom through patented moving grates.

Figure 2-7 is a diagram of the Paraho process. Two basic modes of operation are shown, one with air fed directly into the shale as previously described and an alternate recycling product gas (heated by burning coked spent shale with air).

Development Status:

Prior to 1977 plant tests up to 32 days duration had been completed at the Anvil Points, Colorado facility. An oil yield of 98 percent of the Fischer-Assay was reported with an additional yield of 850 scf of 856 Btu/scf heating value gas per ton of shale retorted.

2.4.2 PRODUCT

Subsequently, 100,000 barrels of crude Paraho shale oil were produced and sent to a major oil refinery for refining into military specification fuels. The reported and published preliminary results¹⁶ in early 1979 indicated that fuels meeting military specifications (JP-5, gasoline and diesel fuel marine) and possessing good storage stability can be produced from crude

shale oil. It was also demonstrated that crude shale oil can be processed in commercial refinery equipment.

Tables 2-9, 2-10 and 2-11 present the chemical and physical properties of Paraho shale oils which are considered candidates for further treatment to produce proper gas turbine fuels.

2.5 TOSCO II SHALE OIL PROCESS

Process Type:	Pyrolysis, Direct
Main Products:	Fuel oil, High-Btu gas
Development Status:	Pilot Plant
Process Developer:	Tosco Corporation (Colony Project)
Process Sponsor:	Tosco Corporation

2.5.1 PROCESS DESCRIPTION (refer to figure 2-8)

Shale is heated and lifted by the hot flue gas from the ball heater in the lift pipe. The preheated feed is contacted with heated ceramic balls in a rotating drum retort. The ceramic balls are separated from the spent shale in a trommel screen at the outlet of the retort. The spent shale generates steam in the cooler. The ceramic balls are elevated and charged to the ball heater where they are heated to the required temperature by burning fuel gas. Pyrolytic vapors are cooled and the gas, tar, and water separated.

2.5.2 OPERATING CONDITIONS¹⁷

Temperature:	800 - 1000°F pyrolysis
Pressure:	atmospheric
Residence time:	5 - 10 min.
Vehicle:	rotating drum
Reaction variables:	reactor temperature
Oil shale feed particle size:	minus 1/2 inch

2.5.3 UNIQUE FEATURES OF PROCESS

- The use of ceramic balls - the balls, which are heated by direct firing of a fuel gas, act to transfer heat and grind up the coal in the pyrolysis drum and trommel.
- A rotating pyrolysis reactor.
- The TOSCO II process recovers as oil or gas substantially 100 weight percent of the total hydrocarbons produced as oil or gas by Fischer Assay. The valuable light gases produced (H_2 , CO and C_1 through C_4 hydrocarbons) are some 20 weight percent of the C_5 and heavier crude shale oil produced.

A. Development Status:

A 1,000-TPD oil-shale, semi-works plant has operated at Parachute Creek, Colorado. Several 50,000-BPD oil-from-shale plants using TOSCO II have been proposed.¹⁸

The process and various equipment used in the process have several patents applied to it for the retorting of shale.

The development work was performed by Tosco Corporation at the Rocky Flats Research Center, Golden, Colorado.

B. History:

TOSCO, in cooperation with other companies, had developed the TOSCO II process for the retorting of oil shale. The process has been demonstrated at the 1000-TPD semi-works plant at Parachute Creek, Colorado. At the present time, there have been several commercial size plants proposed to produce approximately 50,000-BPD of shale oil.

Early in April, 1980 Tosco Corporation announced they were making plans for the construction of a 50,000 BPD commercial plant.

2.5.4 UPGRADING OF PRODUCTS¹⁹

Plans for commercial oil shale processing by Colony include upgrading principally for the purpose of removing nitrogen compounds abundantly present in crude shale oil. These compounds are catalyst poisons in refining processes such as reforming, catalytic cracking and hydrocracking. Nitrogen compounds also contribute to formation of nitrogen oxides when oil is burned in conventional combustion equipment. Crude shale oil has a nitrogen content of about 1.9 weight percent. For comparison, heavy crude oil from the Los Angeles basin, one of the highest nitrogen crude oils processed in this country, contains about 0.6 weight percent nitrogen.

The proposed Colony upgrading units, as shown by Figure 2-9, include coking, hydrotreating of gas oil and naphtha, gas treating, hydrogen production and recovery of ammonia and sulfur. Upgrading with the units described above has benefits in addition to removal of nitrogen. Table 2-12, 2-13 and 2-14 show the properties of crude shale oil, bottomless crude shale oil and the hydrotreated oil produced by upgrading for the proposed Colony design.

As shown, the hydrotreated oil is a sulfur free distillate product low in nitrogen content. In addition to removing sulfur and nitrogen, upgrading reduces the viscosity of the oil, thus reducing pipeline transportation costs, and eliminates, by the coking step, any processed shale residue that may be present in the crude shale oil.

2.5.5 PROBLEM AREAS

- Ceramic ball attrition.
- Process efficiency can be expected to be lowered due to low pressure operation and ceramic ball system.

2.6 SYNCRUDE COSTS

The estimated fixed capital investment (FCI) costs and estimated required product selling prices (RPSP) for the syncrude products produced by the above described processes from published literature are listed in Table 2-15. For

purposes of comparison, published cost estimates were adjusted to a uniform plant capacity of 100,000 barrels per day of product equivalent and early 1980 dollars. The price per barrel range of \$21 to \$25 for the syncrudes appear competitive with current crude oil import prices.

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F			
HYDROGEN, WT %	11.6			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F	0.95		
NITROGEN TOTAL, WT %	.3			122°F			
SULFUR TOTAL, WT %	.2			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %	4.9			100°F			
OLEFINS, VOL %	26.4			122°F			
NAPHTHENES, VOL %	57.0			210°F			
AROMATICS TOTAL, VOL %	10.3			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB	18597		
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	< 10.	ASTM D-482		TOR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al	2.3		
WATER, VOL %				As	.005		
WATER & SEDIMENT, VOL %	0.5			Ba			
WAX, WT %				Ca	.08		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu	detected		
				Fe, total	.4		
				Hg	ND(.02)		
				K	.07		
				Mg	.01		
				Mn			
				Mo			
				Na	.3		
				Ni	.1		
				Pb	.2		
				Se			
				Si	34.		
				Ti	ND(2)		
				V	.1		
				Zn			
VOLATILITY		ASTM D-86					
DISTILLATION TEMP., °F MAX		98					
INITIAL BOILING POINT		182					
10% EVAPORATED		322					
50% EVAPORATED		400					
90% EVAPORATED		452					
FINAL BOILING POINT							
RESIDUE, VOL %							
FLASH POINT, °F		9.					
GRAVITY, °API		35.					
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
Carbon wt%	84.9	Molecules wt	110.				
Oxygen wt%	3.0						
Chlorine ppm	5.						
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE Naphtha H-Coal Source			
RMP JOB NO. 6009-1 TABLE 2-1				FROM REFERENCE A-036 "Analytical Studies for the H-Coal Process"			
				SHEET ____ OF ____			

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F		-35	
HYDROGEN, WT %	9.7			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F		3.369	
NITROGEN TOTAL, WT %	0.4			122°F		1.224	
SULFUR TOTAL, WT %	0.1			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %	46.			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB		18068	
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %				JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F	10	ASTM D-482		TDR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al		1.5	
WATER & SEDIMENT, VOL %				As		.005	
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca		.1	
				Cd			
				Cr, total			
				Cu			
				Fe, total		2.2	
				Hg		.14	
				K		.03	
				Mg		.01	
				Mn			
				Mo			
				Na		.2	
				Ni		.1	
				Pb		.1	
				Se			
				Si		ND(5)	
				Ti		ND(2)	
				V		.2	
				Zn			
VOLATILITY		ASTM D-2887		ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	408						
10% EVAPORATED	443						
50% EVAPORATED	509						
90% EVAPORATED	583						
FINAL BOILING POINT	657						
RESIDUE, VOL %							
FLASH POINT, °F	225.						
GRAVITY, °API	15.1						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES Wt% of 400°F+ Cut	90.3						
Carbon Wt%	88.8	Molecule Wt 180.					
Oxygen	1.0						
Chlorine ppm	28.						
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE 400 - 650°F B-Coal Source			
RMP JOB NO. 6009-1 TABLE 2-2				FROM REFERENCE A-036			
				SHEET ____ OF ____			

COMPOSITION	TEST METHOD	FLUIDITY	TEST METHOD
CARBON, WT %		POUR POINT, °F	-45 ASTM D-97
HYDROGEN, WT %		VISCOSITY, KINEMATIC, cS	
OXYGEN, WT %		100°F	4.16 ASTM D-445
NITROGEN TOTAL, WT %		122°F	
SULFUR TOTAL, WT %	0.1	210°F	
SULFUR, MERCAPTAN, WT %		VISCOSITY, SAYBOLT UNIV., SEC	
PARAFFINS, VOL %		100°F	
OLEFINS, VOL %		122°F	
NAPHTHENES, VOL %		210°F	
AROMATICS TOTAL, VOL %		COMBUSTION	
NAPHTHALENES, VOL %		NET HEAT OF COMB., BTU/LB	18039 ASTM D-2382
POLYNUCLEAR AROMATICS, VOL %		GROSS HEAT OF COMB., BTU/LB	
CARBON RESIDUE ON 10%, WT%	2.52	THERMAL STABILITY	
ON 100%, WT%		JFTOT, BREAKPOINT TEMP., °F	
ASH, WT %	ASTM D482	TOR ΔP	
ASH MELT TEMPERATURE, °F		TRACE METAL ANALYSIS, PPM	
FILTERABLE DIRT, MG/100 ML			
WATER, VOL %			
WATER & SEDIMENT, VOL %	31.6		
WAX, WT %			
WAX, MELT TEMPERATURE, °F			
VOLATILITY			
DISTILLATION TEMP., °F MAX	ASTM D-1160		
INITIAL BOILING POINT	414		
10% EVAPORATED	472		
50% EVAPORATED	514		
90% EVAPORATED	592		
FINAL BOILING POINT	670		
RESIDUE, VOL %			
FLASH POINT, °F	235 ASTM D-5693		
GRAVITY, °API	13.6 Dig. Density Meter		
GRAVITY, SPECIFIC, 60°F			
100°F			
210°F			
NOTES			
Wt% of 400°F + Cut	100		
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES	
RMP JOB NO. 6009-1 TABLE 2-3		FUEL TYPE 400°F + H-Coal Source	
		FROM REFERENCE A-036	
		SHEET ____ OF ____	

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F		50.	
HYDROGEN, WT %	8.0			VISCOSITY, KINEMATIC, cS		121.7	
OXYGEN, WT %				100°F		6.368	
NITROGEN TOTAL, WT %	1.3			122°F			
SULFUR TOTAL, WT %	0.2			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/L3		17420.	
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/L3			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %	1200	D-482		JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TDR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al		49.	
WATER & SEDIMENT, VOL %				As		.04	
WAX, WT %				Ba		detected	
WAX, MELT TEMPERATURE, °F				Ca		11.	
				Cd		detected	
				Cr, total			
				Cu			
				Fe, total		115.	
				Hg			
				K		3.	
				Mg		3.	
				Mn		detected	
				Mo			
				Na		9.	
				Ni		.3	
				Pb		.2	
				Se			
				Si		50.	
				Ti		ND(2)	
				V		.2	
				Zn			
VOLATILITY		ASTM D-2887		ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	604.						
10% EVAPORATED	634						
50% EVAPORATED	681						
90% EVAPORATED	746						
FINAL BOILING POINT	883						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	1.3						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES Wt% of 400°F + Cut	9.7	Chlorine ppm	ND				
Carbon Wt%	89.2	Molecules Wt	258				
Oxygen Wt%	1.3						
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE 650°F + H-Coal Source			
RMP JOB NO. 6009-1 TABLE 2-4				FROM REFERENCE A-036			
				SHEET ___ OF ___			

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	86.0			POUR POINT, °F	<-45		D 97
HYDROGEN, WT %	9.1			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	3.6-4.3			100°F	3.41		
NITROGEN TOTAL, WT %	0.9-1.1			122°F			
SULFUR TOTAL, WT %	0.2			210°F	1.07		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %	35-58			100°F	36.3-37.3		
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %	<62-65			COMBUSTION			
NAPHTHALENES, VOL %	14-19			NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	16,900		D 240
CARBON RESIDUE ON 10%, WT%	<1.2			THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F	I		D 1661
ASH, WT %	0.001			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni*	0.1		
				Pb			
				Se			
				Si			
				Ti			
				V*	<0.1		
				Zn			
VOLATILITY		D 86		ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	338-396						
10% EVAPORATED	386-406						
50% EVAPORATED	425-444						
90% EVAPORATED	483-500						
FINAL BOILING POINT	538-553						
RESIDUE, VOL %	1						
FLASH POINT, °F	160		D 990				
GRAVITY, °API	13.8						
GRAVITY, SPECIFIC, 60°F	0.974						
NOTES*	Aniline Point °F	<26.2					
	Halides as NaCl, LB/MB	5.0	D 1322				
	Iodine No	25.9					
FUEL QUALITY/PROCESSING STUDY			FUEL PROPERTIES		FUEL TYPE SRC II Middle Distillate		
RMP JOB NO. 6009-1 TABLE 2-5					FROM REFERENCE Gulf Phase Zero Report		
					SRC-II Demonstration Project July 31, 1979		
					Volume 1 of 9, p.A.1-5 SHEET ___ OF ___		

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	89.1			POUR POINT, °F	< + 45		
HYDROGEN, WT %	7.5			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	1.4-1.8			100°F	49.6-90.2		
NITROGEN TOTAL, WT %	1.2-1.4			122°F			
SULFUR TOTAL, WT %	0.37-0.47			210°F	4.0-5.1		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %	--			100°F	342-418		
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F	39.8-42.7		
AROMATICS TOTAL, VOL %	--			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	17,000		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%	<1.5			JFTOT, BREAKPOINT TEMP., °F	1		
ASH, WT %				TDR ΔP	1		
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni *	0.3		
				Pb			
				Se			
				Si			
				Ti			
				V *	<0.1		
				Zn			
VOLATILITY		D 1160		ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	538-554						
10% EVAPORATED	568-584						
50% EVAPORATED	640-656						
90% EVAPORATED	785-820						
FINAL BOILING POINT	928-939						
RESIDUE, VOL %	None Given						
FLASH POINT, °F	>180						
GRAVITY, °API							
GRAVITY, SPECIFIC, 60°F	1.072						
100°F							
210°F							
NOTES *							
Aniline Point, °F	68						
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE SRC II Heavy Distillate			
RMP JOB NO. 6009-1				FROM REFERENCE Gulf Phase Zero Report			
TABLE 2-6				SRC-II Demonstration Project July 31, 197			
				Volume 1 of 9, p.A1-5 SHEET ___ OF ___			

COMPOSITION

CARBON, WT %
HYDROGEN, WT %
OXYGEN, WT %
NITROGEN TOTAL, WT %
SULFUR TOTAL, WT %
SULFUR, MERCAPTAN, WT %
PARAFFINS, VOL %
OLEFINS, VOL %
NAPHTHENES, VOL %
AROMATICS TOTAL, VOL %
NAPHTHALENES, VOL %
POLYNUCLEAR AROMATICS, VOL %
CARBON RESIDUE ON 10%, WT %
ON 100%, WT %
ASH, WT %
ASH MELT TEMPERATURE, °F
FILTERABLE DIRT, MG/100 ML
WATER, VOL %
WATER & SEDIMENT, VOL %
WAX, WT %
WAX MELT TEMPERATURE, °F

VOLATILITY

DISTILLATION TEMP., °F MAX
INITIAL BOILING POINT
10% EVAPORATED
50% EVAPORATED
90% EVAPORATED
FINAL BOILING POINT
RESIDUE, VOL %
FLASH POINT, °F
GRAVITY, °API
GRAVITY, SPECIFIC, 60°F
102°F
210°F

NOTES

TEST METHOD

[illegible]

FLUIDITY

POUR POINT, °F
VISCOSITY, KINEMATIC, cS
100°F
122°F
210°F
VISCOSITY, SAYBOLT UNIV., SEC
100°F
122°F
210°F

COMBUSTION

NET HEAT OF COMB., BTU/LB
GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
TDR ΔP

TRACE METAL ANALYSIS, PPM

Al	
As	
Ba	
Ca	0.35
Cd	
Cr, total	
Cu	
Fe, total	61.0
Hg	
K	0.19
Mg	
Mn	
Mo	
Na	0.39
Ni	
Pb	0.9
Se	
Si	
Ti	20
V	0.9
Zn	

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TEST METHOD

[illegible]

FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE 2-6a

FUEL PROPERTIES

FUEL TYPE SRC Raw Process Solvent

FROM REFERENCE A-073-P

SHEET ____ OF ____

COMPOSITION		TEST METHOD	FLUIDITY		TEST METHOD
CARBON, WT %			POUR POINT, °F	- 36.0	
HYDROGEN, WT %	9.95		VISCOSITY, KINEMATIC, cS		
OXYGEN, WT %	0.33		100°F	2.67	
NITROGEN TOTAL, WT %	0.08		122°F		
SULFUR TOTAL, WT %	0.03		210°F	1.11	
SULFUR, MERCAPTAN, WT %			VISCOSITY, SAYBOLT UNIV., SEC		
PARAFFINS, VOL %			100°F		
OLEFINS, VOL %			122°F		
NAPHTHENES, VOL %			210°F		
AROMATICS TOTAL, VOL %			COMBUSTION		
NAPHTHALENES, VOL %			NET HEAT OF COMB., BTU/LB		
POLYNUCLEAR AROMATICS, VOL %			GROSS HEAT OF COMB., BTU/LB	18,343	
CARBON RESIDUE ON 10%, WT% ON 100%, WT%			THERMAL STABILITY		
ASH, WT %	0.0		JFTOT, BREAKPOINT TEMP., °F		
ASH MELT TEMPERATURE, °F			TOR ΔP		
FILTERABLE DIRT, MG/100 ML			TRACE METAL ANALYSIS, PPM		
WATER, VOL %			Al		
WATER & SEDIMENT, VOL %			As		
WAX, WT %			Ba		
WAX, MELT TEMPERATURE, °F			Ca	2.6	
			Cd		
			Cr, total		
			Cu		
			Fe, total	3.1	
			Hg		
			K	1.2	
			Mg		
			Mn		
			Mo		
			Na	12.0	
			Ni		
			Pb	0.3	
			Se		
			Si		
			Ti	0.07	
			V	0.02	
			Zn		
VOLATILITY		ASTM D-1160			
DISTILLATION TEMP., °F MAX					
INITIAL BOILING POINT	194				
10% EVAPORATED	373				
50% EVAPORATED	454				
90% EVAPORATED	642				
FINAL BOILING POINT	694				
RESIDUE, VOL %					
FLASH POINT, °F	101.0				
GRAVITY, °API	16.0				
GRAVITY, SPECIFIC, 60°F					
100°F					
210°F					
NOTES					
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE EDS Fuel No. 5	
RMP JOB NO. 6009-1 TABLE 2-7				FROM REFERENCE Combustion Effects of Coal Liquid & Other Synthetic Fuels in Gas Turbine Combustors - Part I. ASME Conference Paper 80-GT-61	

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUP POINT, °F	- 36.0		
HYDROGEN, WT %	10.16			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.48			100°F	2.34		
NITROGEN TOTAL, WT %	0.044			122°F			
SULFUR TOTAL, WT %	0.02			210°F	1.00		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	18,400		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.001			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				3a			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY		ASTM D-1160		ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT (5%)	409						
10% EVAPORATED	419						
50% EVAPORATED	499						
90% EVAPORATED	584						
FINAL BOILING POINT	608						
RESIDUE, VOL %							
FLASH POINT, °F	122.0						
CRAVITY, °API	17.1						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE EDS Fuel No. 5 Reprocessed			
RMP JOB NO. 6009-1 TABLE 2-8				FROM REFERENCE Paper 80-GT-67			
				SHEET ____ OF ____			

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	84.8			POUR POINT, °F	85		
HYDROGEN, WT %	11.4			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	1.3			100°F			
NITROGEN TOTAL, WT %	2.0			122°F			
SULFUR TOTAL, WT %	0.6			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F	> 83		
NAPHTHENES, VOL %				210°F	48		
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As	12		
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	33		
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni	2.0		
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn	0.2		
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT							
10% EVAPORATED							
50% EVAPORATED							
90% EVAPORATED							
FINAL BOILING POINT							
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	21.4						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
650°F - Vol.%	32	Mol wt. 297					
650°F + Vol.%	68						
Asphaltenes, wt.%	0.58						
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE Paraho Settled Shale Oil			
RMP JOB NO. 6009-1 TABLE 2-9				FROM REFERENCE B-014, Refining of Paraho Shale Oil into Military Specification Fuels, 1979		SHEET ___ OF ___	

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COMPOSITION		TEST METHOD	FLUIDITY		TEST METHOD
CARBON, WT %	85.9		POUR POINT, °F		
HYDROGEN, WT %	13.0		VISCOSITY, KINEMATIC, cS		
OXYGEN, WT %	0.5		100°F		
NITROGEN TOTAL, WT %	0.3		122°F		
SULFUR TOTAL, WT %	< 0.002		210°F		
SULFUR, MERCAPTAN, WT %			VISCOSITY, SAYBOLT UNIV., SEC		
PARAFFINS, VOL %			100°F		
OLEFINS, VOL %			122°F		
NAPHTHENES, VOL %			210°F		
AROMATICS TOTAL, VOL %			COMBUSTION		
NAPHTHALENES, VOL %			NET HEAT OF COMB., BTU/LB		
POLYNUCLEAR AROMATICS, VOL %			GROSS HEAT OF COMB., BTU/LB		
CARBON RESIDUE ON 10%, WT%			THERMAL STABILITY		
C N 100%, WT%			JFTOT, BREAKPOINT TEMP., °F		
ASH, WT %			TDR ΔP		
ASH MELT TEMPERATURE, °F			TRACE METAL ANALYSIS, PPM		
FILTERABLE DIRT, MG/100 ML			Al		
WATER, VOL %			As		
WATER & SEDIMENT, VOL %			Ba		
WAX, WT %			Ca		
WAX, MELT TEMPERATURE, °F			Cd		
			Cr, total		
			Cu		
			Fe, total		
			Hg		
			K		
			Mg		
			Mn		
			Mo		
			Na		
			Ni		
			Pb		
			Se		
			Si		
			Ti		
			V		
			Zn		
VOLATILITY			ORIGINAL PAGE IS OF POOR QUALITY		
DISTILLATION TEMP., °F MAX					
INITIAL BOILING POINT					
10% EVAPORATED					
50% EVAPORATED					
90% EVAPORATED					
FINAL BOILING POINT					
RESIDUE, VOL %					
FLASH POINT, °F					
GRAVITY, °API	34.4				
GRAVITY, SPECIFIC, 60°F					
100°F					
210°F					
NOTES					
650°F ~, Vol%		65			
Molecular wt		261			
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE <u>Paraho Hydrotreated Whole</u>	
RMP JOB NO. 6009-1 TABLE 2-10				FROM REFERENCE <u>Shale Oil</u>	
				B-014	
				SHEET ____ OF ____	

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	87.32			POUR POINT, °F	105		
HYDROGEN, WT %	12.59			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.0102			100°F			
NITROGEN TOTAL, WT %	0.33			122°F	25.71		
SULFUR TOTAL, WT %	0.0005			210°F	6.45		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV, SEC			
PARAFFINS, VOL %	57.1			100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %	42.9			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %	Nil	D482		JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TOR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al			
WATER & SEDIMENT, VOL %				As	0.1		
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca			
				Cd			
				Cr, total			
				Cu			
				Fe, total	0.9		
				Hg			
				K	<0.1		
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V	0.4		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT							
10% EVAPORATED							
50% EVAPORATED							
90% EVAPORATED							
FINAL BOILING POINT							
RESIDUE, VOL %							
FLASH POINT, °F	300						
GRAVITY, °API	30.3						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES	Asphaltenes, Wt%	0.244					
	Molecular Wt	351					
FUEL QUALITY/PROCESSING STUDY				FUEL PROPERTIES		FUEL TYPE Paraho 650°F+ Bottoms	
RMP JOB NO. 6009-1 TABLE 2-11						FROM REFERENCE B-014	
						SHEET ____ OF ____	

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2-39

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	80.5			POUR POINT, °F	80		
HYDROGEN, WT %	10.3			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	5.8			100°F			
NITROGEN TOTAL, WT %	1.9			122°F			
SULFUR, TOTAL, WT %	0.7			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F	96		
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %				JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TDR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al			
WATER & SEDIMENT, VOL %				As			
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca			
				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	< 400						
10% EVAPORATED	< 400						
50% EVAPORATED	< 650						
90% EVAPORATED	< 950						
FINAL BOILING POINT	> 950						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	21						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							

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FUEL QUALITY/PROCESSING STUDY RMP JOB NO. 6009-1 TABLE 2-12	FUEL PROPERTIES	FUEL TYPE TOSCO Crude Shale Oil FROM REFERENCE "Oil Shale Economics Update", Tosco Corp. April 18, 1978 SHEET ____ OF ____
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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	55		
HYDROGEN, WT %				VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F			
NITROGEN TOTAL, WT %	1.8			122°F			
SULFUR TOTAL, WT %	0.7			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F	48		
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	< 400						
10% EVAPORATED	< 400						
50% EVAPORATED	< 650						
90% EVAPORATED	< 950						
FINAL BOILING POINT	< 950						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	25						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
FUEL QUALITY/PROCESSING STUDY				FUEL PROPERTIES			
RMP JOB NO. 6009-1 TABLE 2-13				FUEL TYPE <u>Tosco Bottomless Crude</u>			
				FROM REFERENCE <u>Shale Oil</u>			
				SHEET ____ OF ____			

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	50		
HYDROGEN, WT %				VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F			
NITROGEN TOTAL, WT %	0.06			122°F			
SULFUR TOTAL, WT %	0.01			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F	35		
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	< 400						
10% EVAPORATED	< 400						
50% EVAPORATED	> 400						
90% EVAPORATED	> 650						
FINAL BOILING POINT	< 950						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	40						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							

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FUEL QUALITY/PROCESSING STUDY RMP JOB NO. 6009-1 TABLE 2-14	FUEL PROPERTIES	FUEL TYPE <u>Tosco Hydrotreated Shale Oil</u> FROM REFERENCE _____ <div style="text-align: right;">SHEET ____ OF ____</div>
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Table 2-15

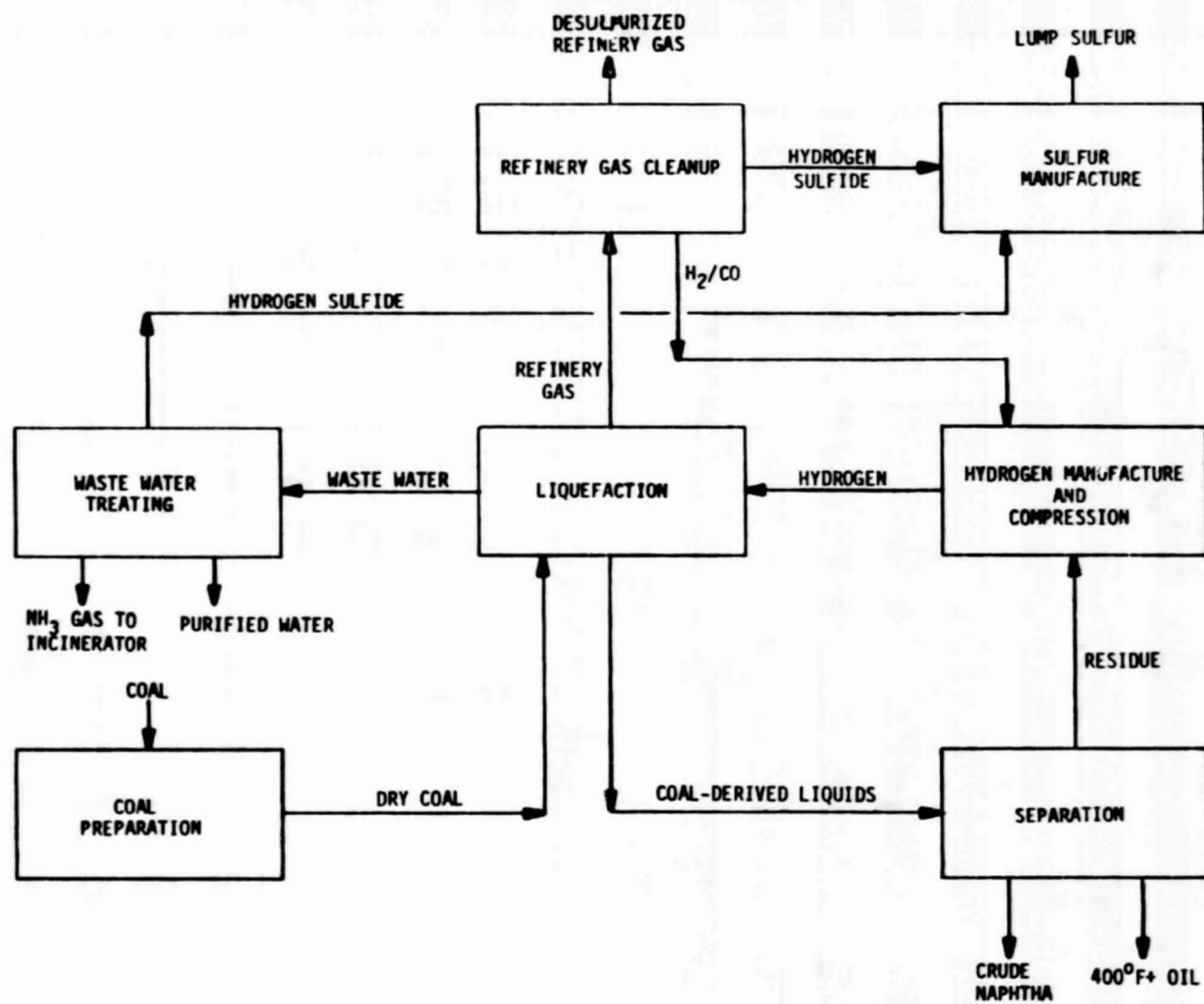
Crude Synthetic Liquid Fuels

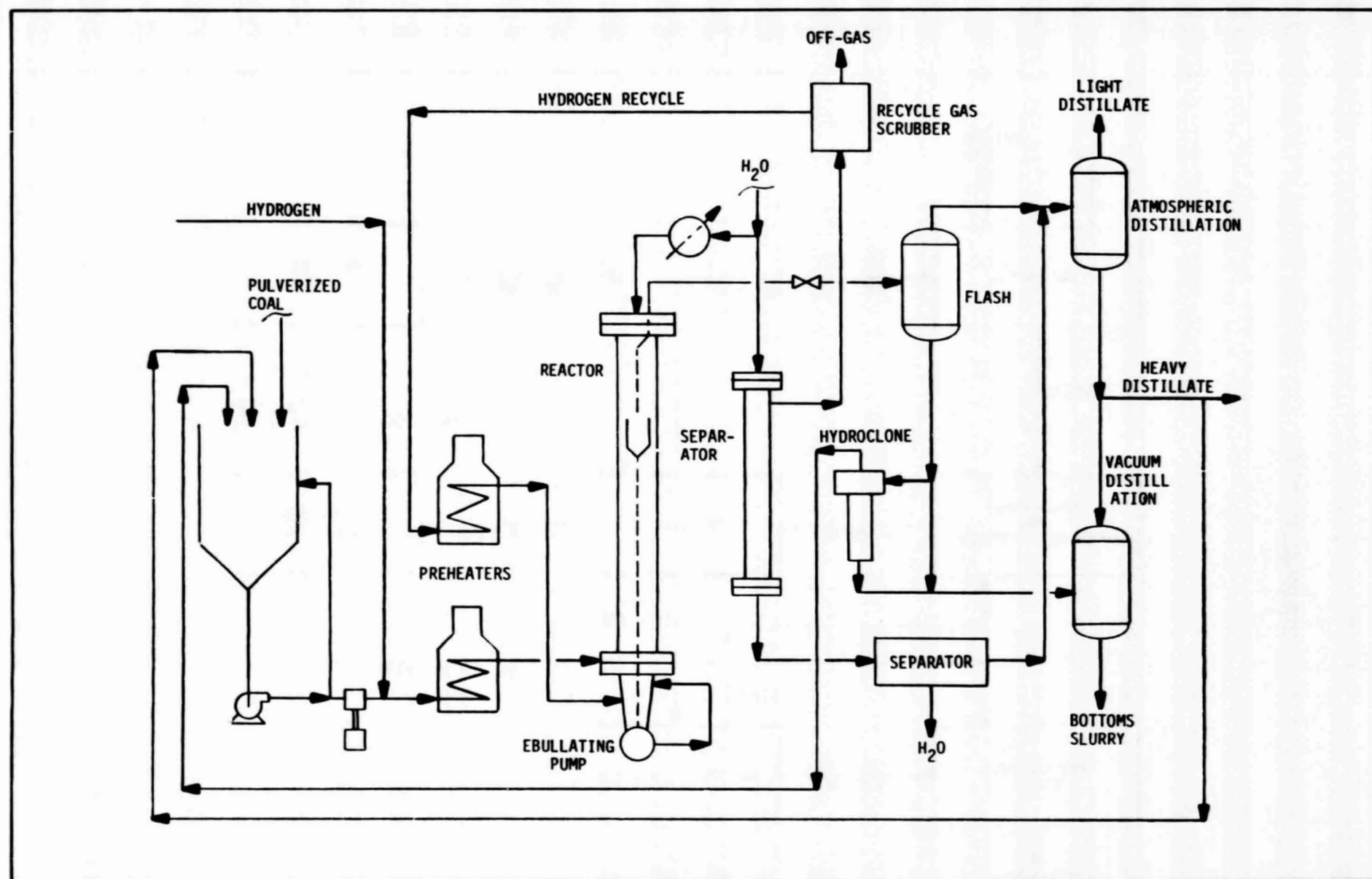
Cost Comparisons^{a, b}

Process	Plant Capacity BPD Equiv. Output	FCI \$ Billion 1980 \$	Cost 12% DCF \$/Bbl (1980)
1. H-Coal ²⁰	100,000	1.83	25
2. SRC II ²¹	100,000	1.87	25
3. Exxon Donor Solvent ²²	100,000	1.88	25
4. Paraho ²³	100,000	1.75	21
5. TOSCO II ²⁴	100,000	1.95	21

^a The U.S. average selling price²⁵ of No. 2 oil is \$31.80 per barrel (bbl).

^b The figures presented are the result of equalizing plant capacities and escalation of capital and operating costs to early 1980 estimated levels. Accordingly, these figures are deemed to represent order of magnitude costs estimates.

ORIGINAL PAGE IS
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Figure 2-2 - H-Coal Process Development Unit³

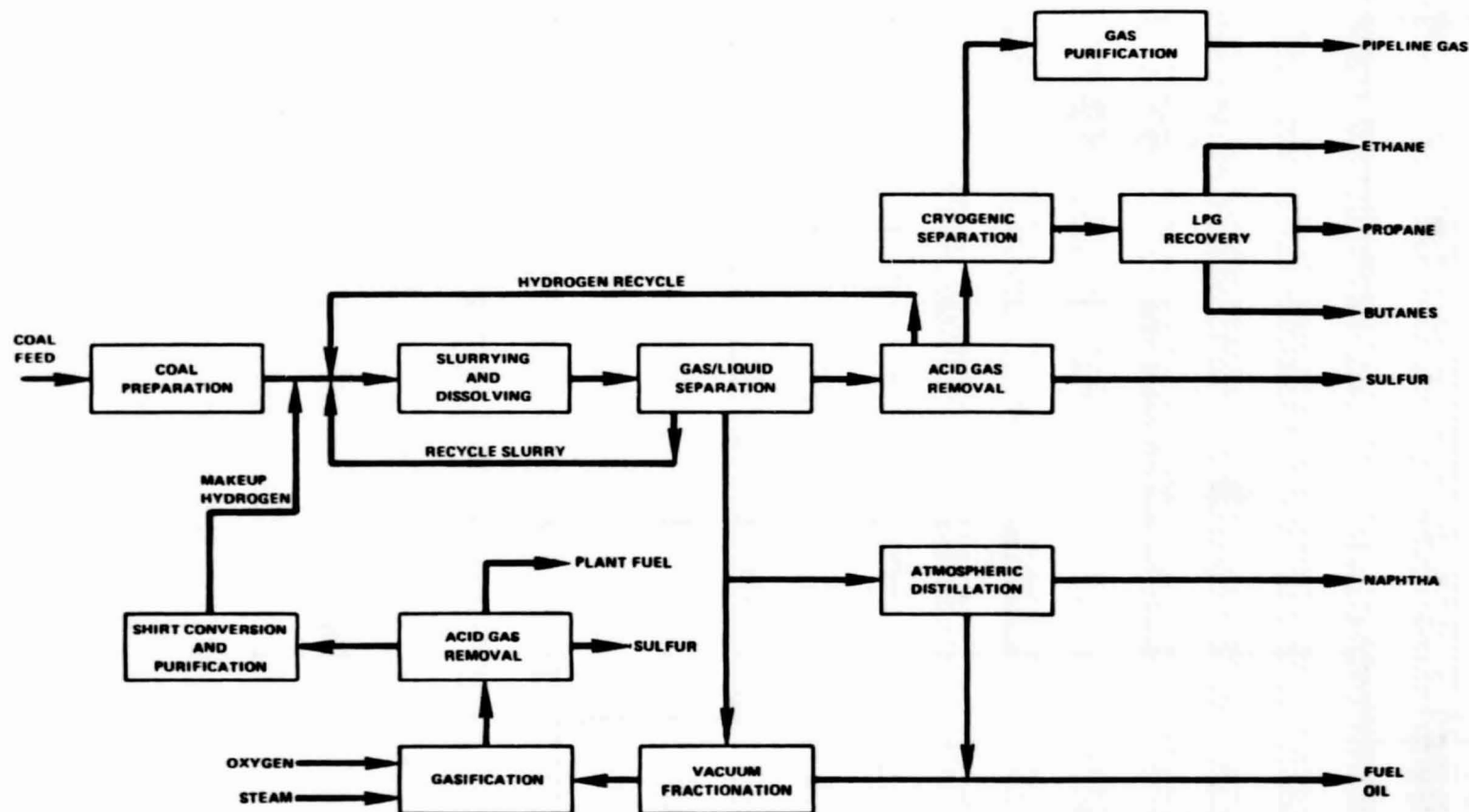
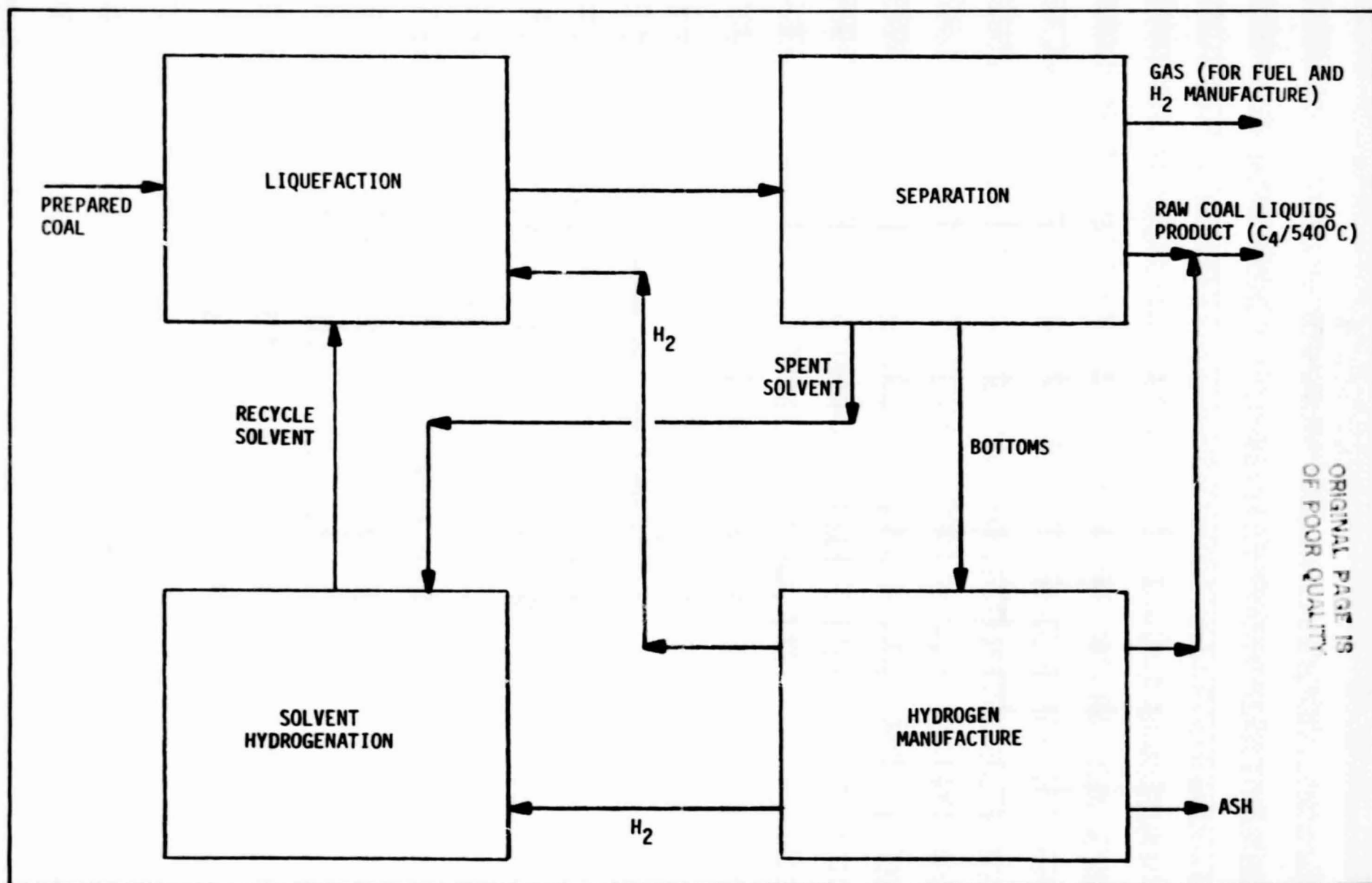


Figure 2-3 - Simplified Block Flow Diagram,
SRC II Process

Figure 2-4 - EDS Simplified Block Diagram²

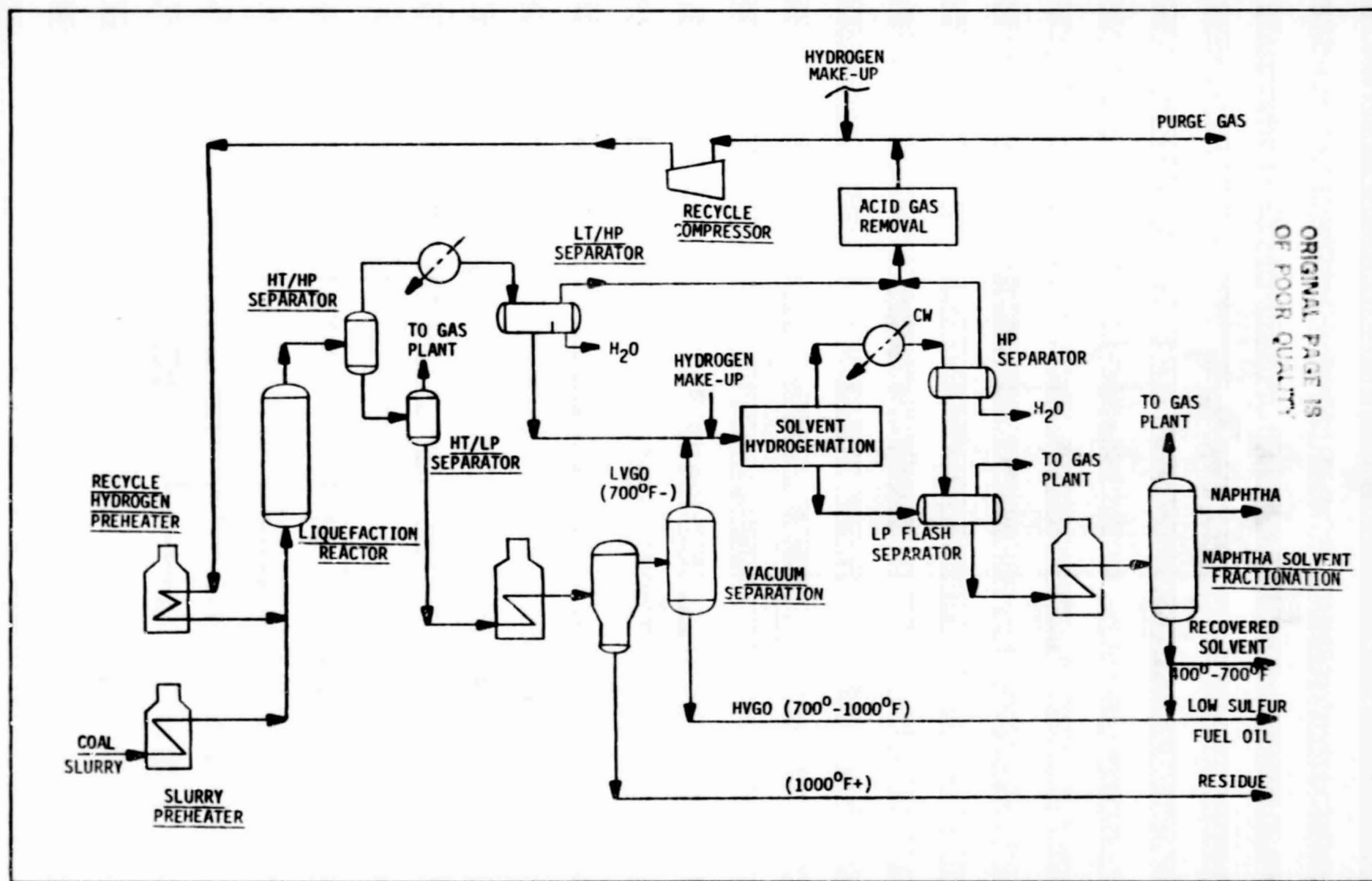


Figure 2-5 - Flow Diagram EDS Liquefaction and Product Separation²

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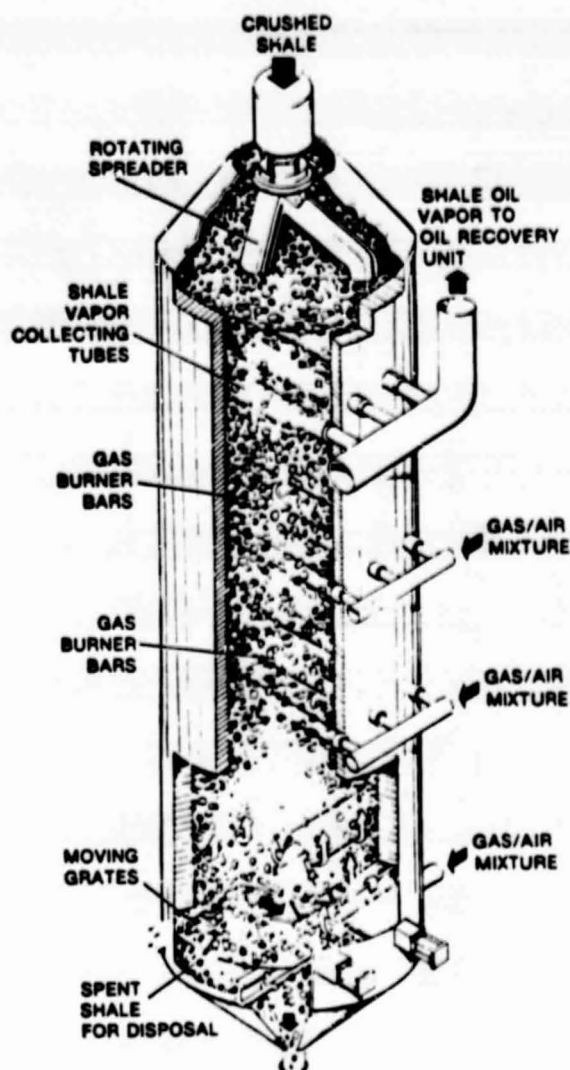


Figure 2-6 - PARAHO Reactor

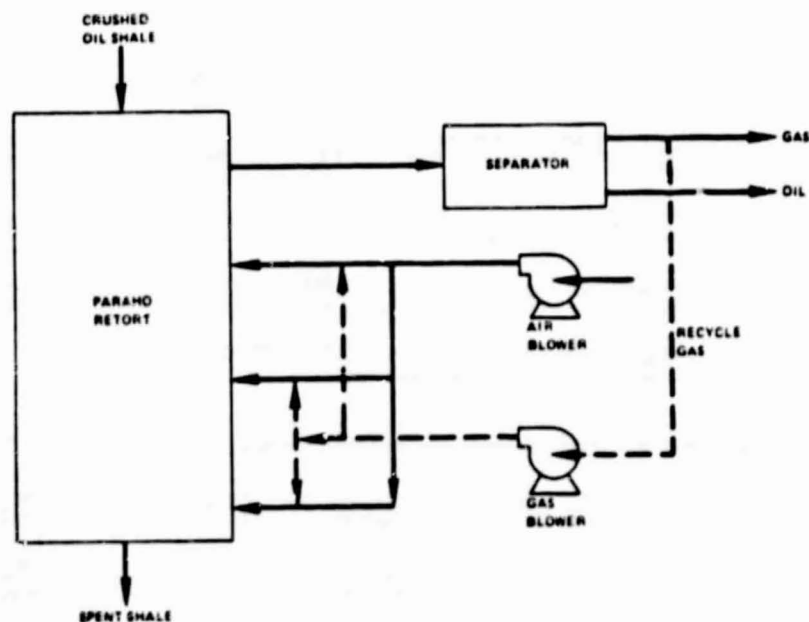


Figure 2-7 - PARAHO Process

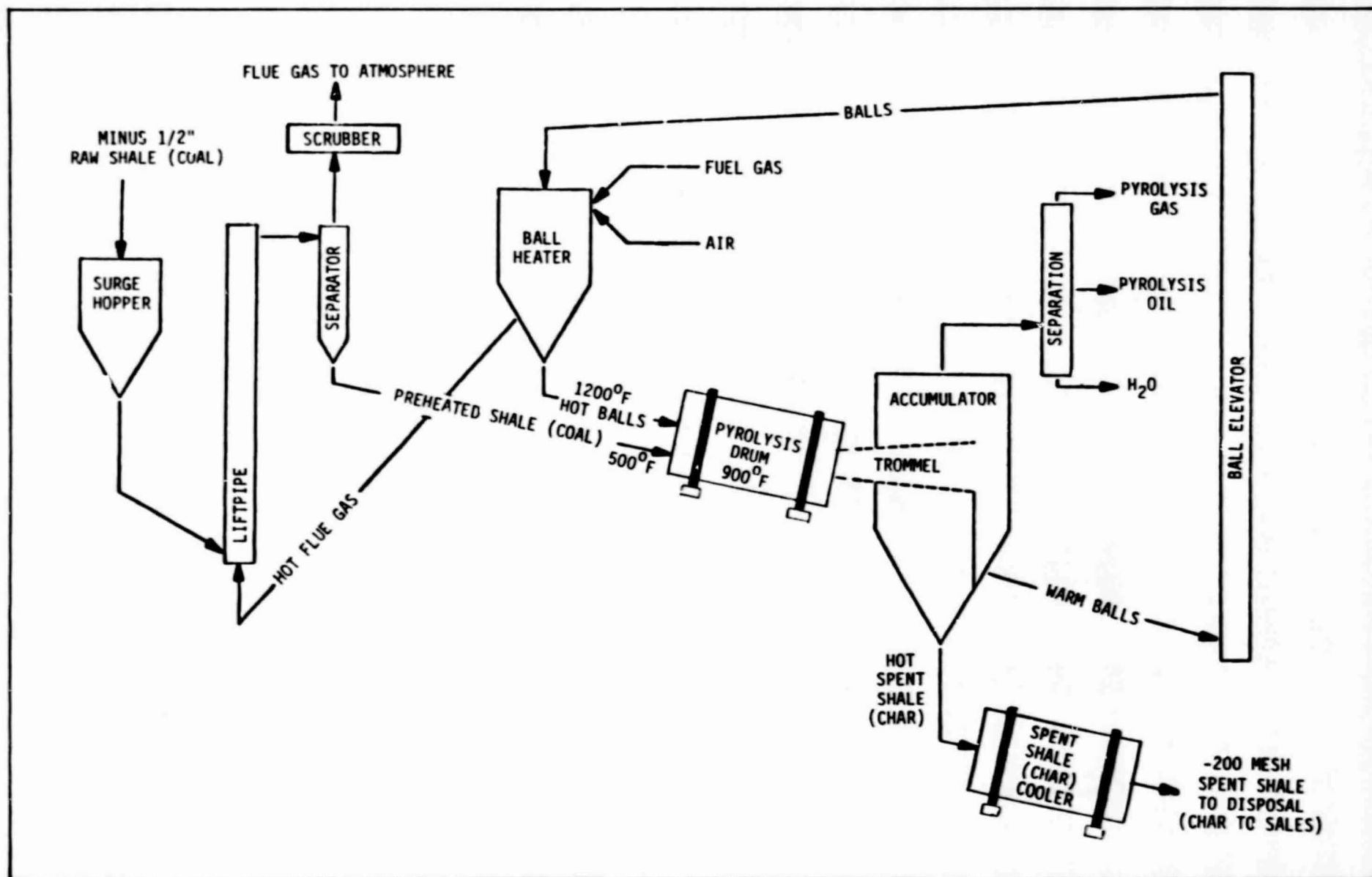


Figure 2-8 - Simplified Flow Diagram,
TOSCO II Shale Oil Process

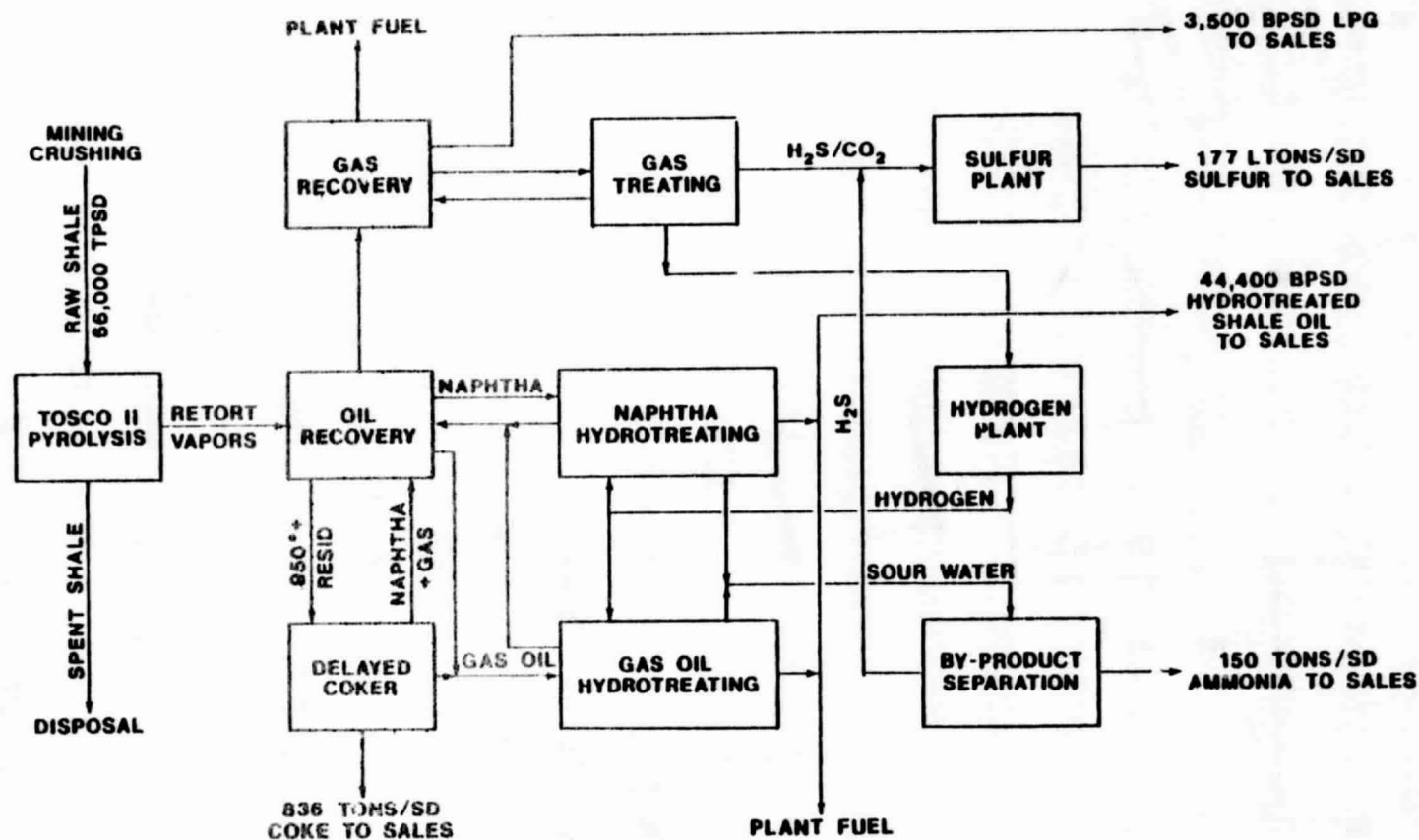


Figure 2-9 - Block Flow Diagram,
Colony Hydrotreated Shale Oil Plant

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SECTION 3
REFINED SYNFUELS PRODUCTION
PROPERTIES AND ECONOMICS

In the previous section established processes which convert coal or oil shale to synthetic liquid are described, together with the character of produced synthetic liquids. In all cases it is likely that some additional refining will be required to produce liquids of turbine fuel quality and to produce saleable by-products.

Development work in the shale conversion field to date has concerned itself with the extent and necessity of hydrogen treatment of the liquid product prior to shipment to the refiner.¹ Part of the concern has centered upon the characteristic unstable nature of the liquid product due to the fact that it is formed by pyrolysis and therefore is olefinic. The second area of concern relates to the extent of treatment that might be necessary to render the synthetic liquid compatible with the severity capabilities of the conventional refinery. This second question is one that applies to all synthetic liquid fuel producing processes and not just those which produce an olefin containing product.

In response to the first concern we recommend that the crude shale oil be hydrogen treated as soon as possible to prevent sludge formation and property change due to polymerization.

The second concern, the concept that syncrude should be converted to a product which is equivalent to crude petroleum is one that serves as the base for much controversy. At the time this idea was first expressed, the ability to assimilate the syncrudes in existing processes was unknown. Since that time considerable work has been done,^{2,3,4} and much is left to be done. The picture is much clearer today, indicating the extent of pretreatment required to render the liquid suitable as feedstock to refinery units. In addition, new processing techniques have been advanced which should have a beneficial effect on processability of syncrude; namely the advancement of residuum hydrocracking and experiments to better define the fluid catalytic cracker performance on nitrogen bearing feedstocks.⁵ Figures 3-1 and 3-2 are simple diagrams depicting hydrocracking processes. Figure 3-3 describes a typical fluid catalytic cracker system with attendant auxiliaries.

All of this work has been directed toward making conventional refinery products. Our present objective is to define the refinery severity necessary to produce acceptable products.

3.1 DISTILLATE FUEL OIL

An analysis is shown in Table 3-1 for a typical range of properties of #2 petroleum fuel oil distillate.⁶ Depending on the sulfur content of the distillate, it may have to be hydrotreated to meet the environmental limits. In all other respects it meets the gas turbine fuel specifications.

3.2 PETROLEUM RESIDUAL OIL

Table 3-2 is an analysis for a typical range of properties of a petroleum residual fuel oil.⁶ This residual fuel oil would be hydrotreated for sulfur removal to meet the environmental limits. It would also require further treatment including inhibiting for metals to meet the gas turbine fuel specifications. Figure 3-4 is a flow diagram describing a typical hydrotreating system.

3.3 COAL DERIVED SYNTHETIC FUELS

3.3.1 H-COAL

An analysis, Table 3-3, of hydrogenated H-Coal syncrude is shown which was obtained from Hydrocarbon Research Inc.⁷ This fuel meets the environmental and gas turbine fuel specifications.

3.3.2 SRC-II

No data has been found to date for SRC-II hydrogenated liquids. Table 3-4 is an analysis of hydrogenated SRC-I raw process solvent.⁷ This fuel oil meets the environmental and gas turbine fuel specifications. The SRC-I raw process solvent analysis was close to a composite of the SRC-II middle and heavy distillates shown in Section 2 Tables 2-5 and 2-6. Hydrogen content was 7.4%. We would expect the SRC-II liquids hydrogen to increase similarly on hydrotreating.

3.3.3 EDS

An analysis of hydrogenated EDS fuel oil is shown in Table 3-5. This oil was obtained from the Exxon Donor Solvent Process.⁸

3.4 OIL SHALE DERIVED SYNTHETIC FUELS

3.4.1 PARAHO

An analysis of highly hydrogenated distillate oil from crude produced by Paraho Company and hydrotreated by SOHIO is shown in Table 3-6.⁹ This meets environmental and gas turbine fuel specifications.

3.5 REFINERY TREATMENT COSTS

The literature search did result in some petroleum treatment cost information. This will require analyses and relating the information to syncrudes, which is to be included in Tasks II, III, IV and V. However, some preliminary figures are presented below based on treatment facilities for 50,000 bbls/day of synthetic crude oil and fractions.

3.5.1 HYDROTREATING COSTS

Capital costs for a hydrotreating unit to desulfurize, denitrogenate and saturate olefinic and polycyclic compounds would approximate \$33 million amounting to \$660 per daily barrel of syncrude capacity. Operating costs approximate 55¢/bbl of feed to the unit.

3.5.2 HYDROCRACKING COSTS

Capital costs for a hydrocracking unit to hydrotreat and hydrocrack a range of syncrude liquids would approximate \$70 million amounting to \$1400 per daily barrel of syncrude capacity. Operating costs approximate \$1.35/bbl of feed to the unit. Certain heavy resids can also be handled.

3.5.3 FLUID CATALYTIC CRACKING COSTS

Capital costs for a fluid catalytic cracking unit to process a range of syncrude liquids would approximate \$72 million amounting to \$1440 per daily barrel of syncrude capacity operating costs approximate \$70/bbl of feed to the unit.

3.6 SUMMARY/CONCLUSIONS

The literature search for this section was directed towards definition of coal and shale syncrude properties after hydrotreating, hydrocracking, and fluid catcracking in a refinery operation (refinery products). The purpose was to produce refined synfuels suitable for use as turbine fuels. Our basic approach for Task I was concerned with hydrotreating to produce refinery products with the follow-up of hydrocracking and fluid cracking.

For tasks III & IV, our efforts would be directed towards references 2 through 4, as key to setting up an LP model for analysis of economics of upgrading an existing refinery vs preparation of syncrude turbine fuels via a new grass roots refinery.

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	87.6-85.9			POUR POINT, °F	-10-30		
HYDROGEN, WT %	12.3-13.2			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F	2.0-4.0		
NITROGEN TOTAL, WT %	0.005-0.06			122°F			
SULFUR TOTAL, WT %	0.1-0.8			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	19,400		
CARBON RESIDUE ON 10%, WT%	0.03-0.3			THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.005	ASTM D-482		TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca	0-2.0		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na +K	0-1.0		
				Ni			
				Pb	0-1.0		
				Se			
				Si			
				Ti			
				V	0-1.0		
				Zn			
VOLATILITY				ASTM D-86			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT							
10% EVAPORATED							
50% EVAPORATED							
90% EVAPORATED	650-675						
FINAL BOILING POINT							
RESIDUE, VOL %							
FLASH POINT, °F	150-200						
GRAVITY, °API							
GRAVITY, SPECIFIC, 60°F	0.82-0.88						
100°F							
210°F							
NOTES							
1) Typical Range of Properties Petroleum Distillate							
FUEL QUALITY/PROCESSING STUDY				FUEL PROPERTIES			
RMP JOB NO. 6009-1 TABLE 3-1				FUEL TYPE #2 Petr. Distillate Fuel Oil			
				FROM REFERENCE A-041 (NASA)			
				SHEET ____ OF ____			

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %		89.5-82.5		POUR POINT, °F		15-95	
HYDROGEN, WT %		10.0-12.5		VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F		100-1800	
NITROGEN TOTAL, WT %		0.05-0.9		122°F			
SULFUR TOTAL, WT %		0.5-4.0		210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB		18,600	
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %		2-10		TDR ΔP			
ASH MELT TEMPERATURE, °F		100-1000		TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca		0-50	
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na + K		1-350	
				Ni			
				Pb		0-25	
				Se			
				Si			
				Ti			
				V		5-400	
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX				ORIGINAL PAGE IS OF POOR QUALITY			
INITIAL BOILING POINT							
10% EVAPORATED							
50% EVAPORATED							
90% EVAPORATED							
FINAL BOILING POINT							
RESIDUE, VOL %							
FLASH POINT, °F		175-265					
GRAVITY, °API							
GRAVITY, SPECIFIC, 60°F		0.92-1.05					
		100°F					
		210°F					
NOTES							

FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE 3-2

FUEL
PROPERTIESFUEL TYPE Petr. Residual Fuel Oil
FROM REFERENCE A-041 (NASA)

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	88.10			POUR POINT, °F			
HYDROGEN, WT %	11.66			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.2			100°F	2.17		
NITROGEN TOTAL, WT %	0.04			122°F			
SULFUR TOTAL, WT %	<0.002			210°F	1.06		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %	27			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB	19,045		
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %				JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TDR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al			
WATER & SEDIMENT, VOL %				As			
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca	0.09		
				Cd			
				Cr, total			
				Cu			
				Fe, total	3.6		
				Hg			
				K	0.04		
				Mg			
				Mn			
				Mo			
				Na	0.36		
				Ni			
				Pb	<1		
				Se			
				Si			
				Ti	<1		
				V	0.1		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX	D-2887						
INITIAL BOILING POINT	325						
10% EVAPORATED	366						
50% EVAPORATED	441						
90% EVAPORATED	563						
FINAL BOILING POINT	733						
RESIDUE, VOL %							
FLASH POINT, °F	175						
GRAVITY, °API	23.2						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
1) H-Coal Raw Distillate Source							
FUEL QUALITY/PROCESSING STUDY				FUEL PROPERTIES			
RMP JOB NO. 6009-1 TABLE 3-3				FUEL TYPE Hydrotreated H-Coal Fuel Oil FROM REFERENCE A-073-P			
				SHEET ____ OF ____			

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COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL %
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT %
 ON 100%, WT %
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL %
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

88.78	
10.99	
0.20	
0.02	
0.01	
34	

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

D-2887

172	
232	
432	
578	
814	
62	
23.4	

NOTES

1) SRC, Raw process solvent source

FLUIDITY

POUR POINT, °F

VISCOSITY, KINEMATIC, cS

100°F

122°F

210°F

VISCOSITY, SAYBOLT UNIV., SEC

100°F

122°F

210°F

COMBUSTION

NET HEAT OF COMB., BTU/LB

GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F

TOR ΔP

TRACE METAL ANALYSIS, PPM

Al

As

Ba

Ca

Cd

Cr, total

Cu

Fe, total

Hg

K

Mg

Mn

Mo

Na

Ni

Pb

Se

Si

Ti

V

Zn

TEST METHOD

2.00	
0.90	
18,903	
0.12	
3.4	
0.01	
0.05	
0.3	
1.0	
<0.1	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE 3-4

FUEL
PROPERTIES

FUEL TYPE Hydrotreated SRC Fuel Oil

FROM REFERENCE A-073-P

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	90.80			POUR POINT, °F			
HYDROGEN, WT %	8.60			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.32			100°F			
NITROGEN TOTAL, WT %	0.24			122°F			
SULFUR TOTAL, WT %	0.04			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB	18,100		
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
VOLATILITY				Cr, total			
DISTILLATION TEMP., °F MAX				Cu			
INITIAL BOILING POINT	392			Fe, total			
10% EVAPORATED	462			Hg			
50% EVAPORATED	657			K			
90% EVAPORATED	774			Mg			
FINAL BOILING POINT	1000			Mn			
RESIDUE, VOL %				Mo			
FLASH POINT, °F				Na			
GRAVITY, °API	8.6			Ni			
GRAVITY, SPECIFIC, 60°F				Pb			
100°F				Se			
210°F				Si			
NOTES				Ti			
1)Exxon Donor Solvent-Raw Liquid Source				V			
				Zn			
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE <u>Hydrotreated EDS Fuel Oil</u>			
RMP JOB NO. 6009-1		TABLE 3-5		FROM REFERENCE <u>A-041</u>			
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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	86.52			POUR POINT, °F	95		
HYDROGEN, WT %	12.80			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.33			100°F	14.45		
NITROGEN TOTAL, WT %	0.33			122°F	3.15		
SULFUR TOTAL, WT %	0.02			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %	14			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	19,365		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
CON. CARBON ON 100%, WT%	0.23			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	<0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca	0.96		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	6.3		
				Hg			
				K	2.6		
				Mg			
				Mn			
				Mo			
				Na	1.4		
				Ni			
				Pb	0.35		
				Se			
				Si			
				Ti	<0.1		
				V	0.12		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX		D-2887					
INITIAL BOILING POINT	421						
10% EVAPORATED	637						
50% EVAPORATED	804						
90% EVAPORATED	924						
FINAL BOILING POINT	1016						
RESIDUE, VOL %							
FLASH POINT, °F	200						
GRAVITY, °API	30.0						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
FUEL QUALITY/PROCESSING STUDY				FUEL PROPERTIES			
RMP JOB NO. 6009-1 TABLE 3-6				FUEL TYPE Shale Oil (Paraho)			
				FROM REFERENCE ASME 80-GT-67			
				SHEET ____ OF ____			

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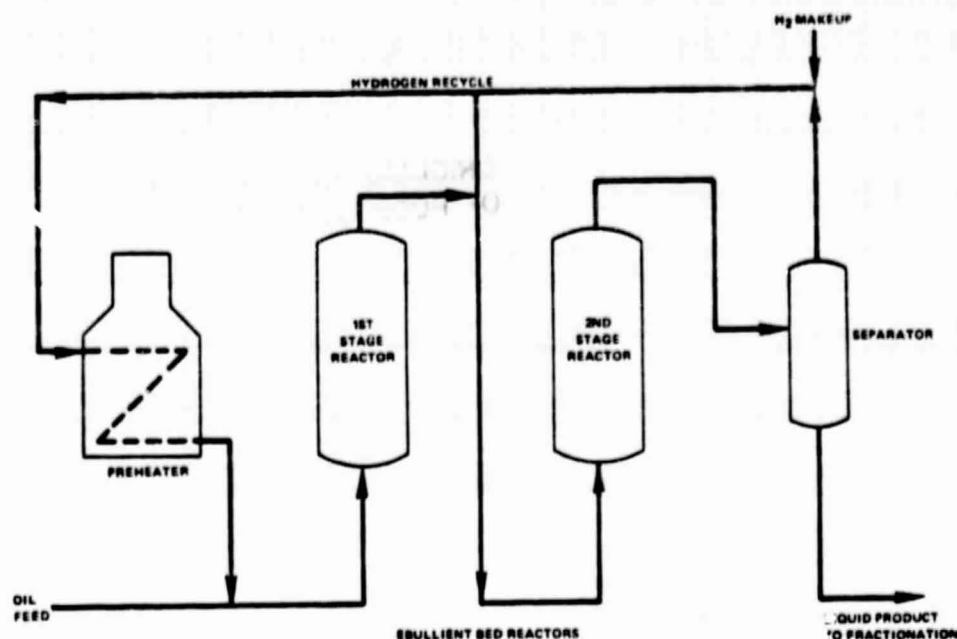


Figure 3-1 - Simplified Flow Diagram,
Heavy Oil Resid Hydrocracker

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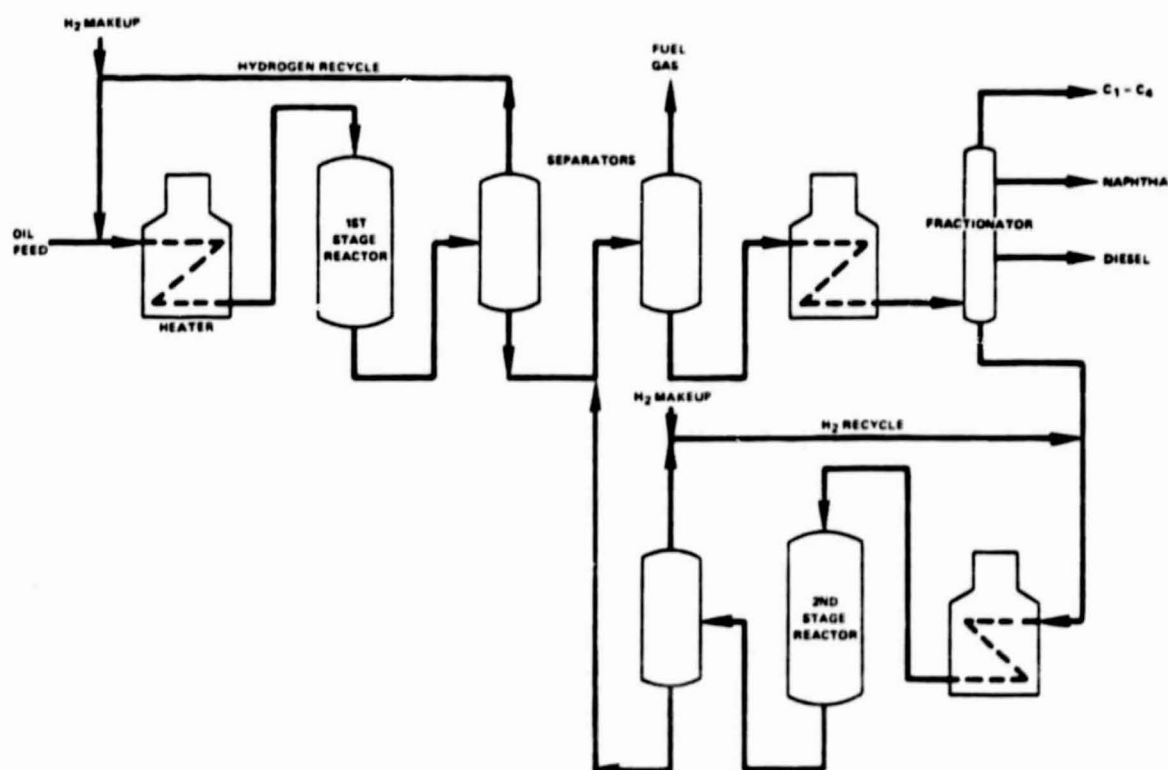


Figure 3-2 - Simplified Flow Diagram,
Two-Stage Hydrocracker

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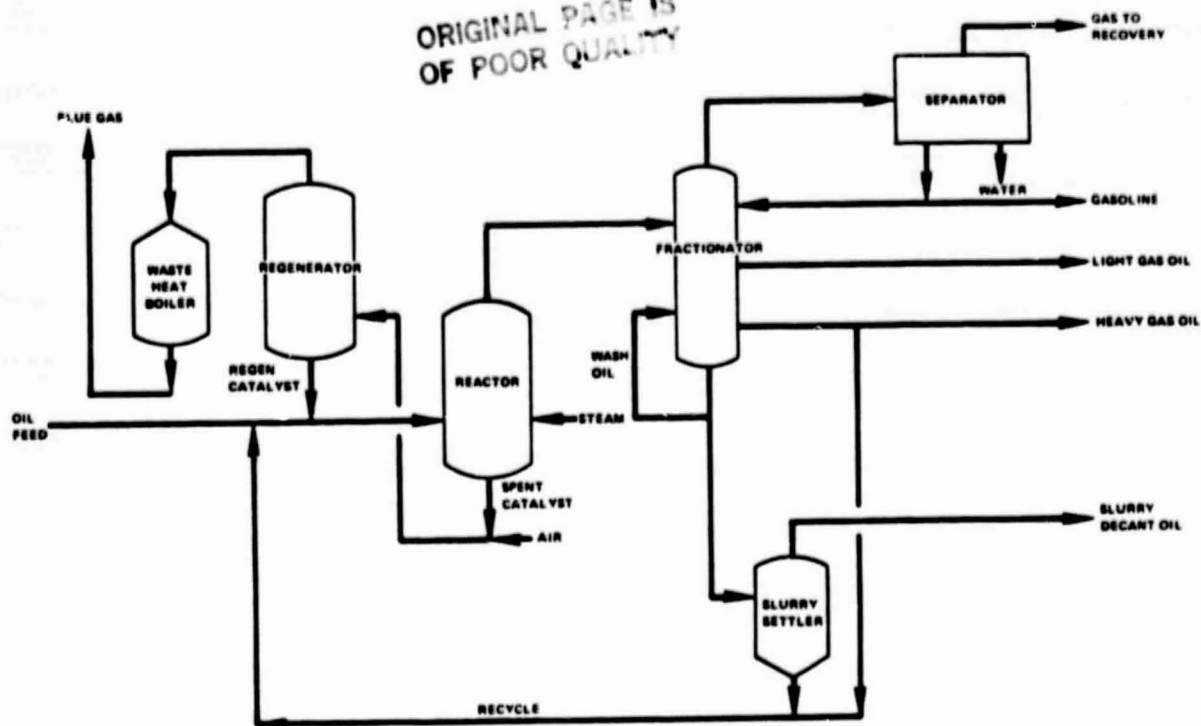


Figure 3-3 - Simplified Flow Diagram,
Fluid Catalytic Cracker

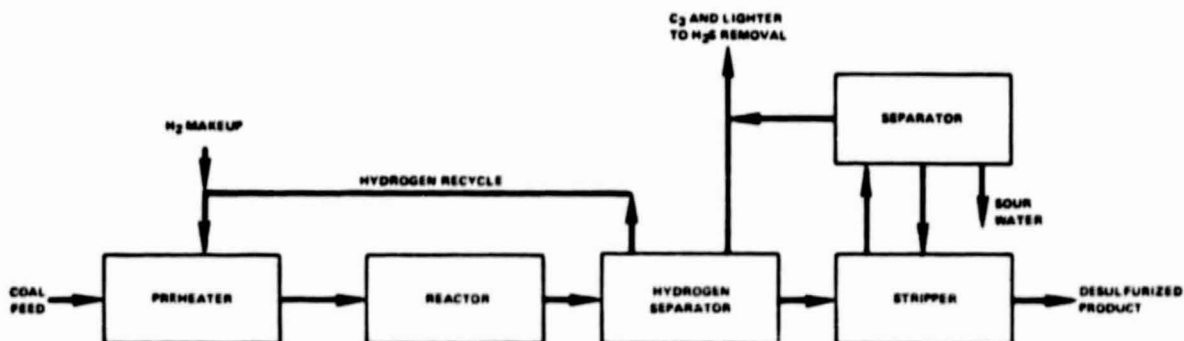


Figure 3-4 - Simplified Block Flow Diagram,
Catalytic Hydrosulfurizer

SECTION 4

GAS TURBINE FUEL CRITERIA

Fuel property specifications covering liquid fuels for gas turbine operation have been developed by the turbine manufacturers from operating experience over the years. As a result each manufacturer has developed a fuel tailored to his specific machine experience and design. Liquid fuels involved have been from petroleum sources.

ASTM has proposed gas turbine fuel property standards. These are also primarily based on manufacturers overall requirements. ASTM has also developed their standard test methods for each specific fuel property determination which have been accepted by the gas turbine manufacturers.

The introduction of new fuels derived from coal and oil shale will call for some specification modifications. However, the expectation is that product tailoring, so that existing specifications will be largely met, will be required. These will be discussed in later sections.

4.1 PRESENT FUEL CRITERIA

Table 4-1 presents the proposed ANSI/ASTM liquid fuel specifications for gas turbines. The last footnote recommends that the turbine manufacturer be consulted.

Tables 4-2, 4-3, 4-4 and 4-5 are liquid fuel specifications for General Electric, Westinghouse, Pratt & Whitney and Brown Boveri industrial and utility gas turbines. The differences in certain of the specification properties relate to the respective combustor and turbine design features allowing limited or greater tolerance to the various individual property effects.

The industrial and utility firms who operate gas turbine units in their systems generally purchase fuels conforming or approaching but not exceeding the specifications set forth by the gas turbine manufacturer. Naturally, there are digressions in fuel characteristics which could give adverse turbine performance

that are nullified by on-site treatment by the operator. The specific pretreatments to make possible the toleration of exceeded specifications are in most cases sanctioned by the turbine manufacturers. The acceptable pretreatment methods are covered in detail in Section 5, On-site Fuel Pretreatment.

4.2 PROJECTED FUTURE FUEL CRITERIA

At this point since coal and oil shale derived liquid fuels are as yet unavailable commercially, future required fuel criteria has taken the form that with present machines the synfuels should be processed such that they will, for the most part, conform to present gas turbine fuel specifications.

4.2.1 MAJOR SYNFUEL DIFFERENCES

Synfuel hydrogen contents tend to be lower than those for accepted petroleum based gas turbine fuels. Coal derived synfuels without subsequent refining processing will be higher in unsaturates and polycyclic hydrocarbon compounds of which a low hydrogen content is indicative. These compounds burn hotter and with an objectionable high smoke level. Current thinking by those working in the field of assessing the suitability of liquid synfuels for present American manufactured gas turbine use is that hydrogen content in the fuel should be greater than 10% by weight. Tests using coal derived fuel oil having hydrogen content of 7.4% in a European gas turbine indicated fully satisfactory performance. Combustion system design was such that this type fuel was handled satisfactorily.

It is our judgement that the market will require that synfuels be refined to a point that they will be similar to the petroleum-based fuels presently used in existing gas turbines. This refining will represent additional processing costs and is covered in Tasks III and IV of this project. When the supply of coal or shale oil-derived synfuels becomes more abundant, it is expected that future gas turbine designs will take into consideration the need for burning synfuels requiring minimal additional process refining or on-site fuel treatment. In any event, existing gas turbines will require synfuels having specifications similar to their petroleum-based specifications until such time that the combustion system can be modified by retrofit to accept synfuels

directly. It is doubtful whether modified combustion processes will be available until synfuel is readily available.

It must be mentioned at this point that the European designed machines, having separately fired combustors which can be easily modified to accept a wide range of fuels and combinations thereof, can more readily accept synfuels.

4.2.2 ENVIRONMENTAL STANDARDS

Currently, in order that gas turbine systems emissions be met, fuel maximum sulfur content has been set at 0.8% and fuel maximum nitrogen content has been set at a value approximately equivalent to 0.3%. Fuels exceeding these standards are considered to require altered combustion procedures, stack gas emission scrubbing or catalytic conversion of the resulting pollutants to an acceptable form. Technical aspects are covered in greater detail in Section 7, Turbine Emission Controls.

It should be noted where water injection is used for NO_x control, particularly when burning the "hotter" fuels, that total trace elements in the fuel and injection water shall not exceed fuel specification requirements.

Table 4-1
Proposed ASTM and ANSI Liquid Fuel
Specifications for Gas Turbines

Property	ASTM Test Method	No. 2-GT	No. 3-GT	No. 4-GT
Gravity, °API, Min.	D287	30	-	-
Kin. Visc., cs, 100°F, Min.	D445	2.0	-	-
Kin. Visc., cs, 100°F, Max.	D445	4.3	-	-
Flash Point, °F, Min.	D93	100	130	150
Dist. Temp., 90% Point, °F, Min.	D86	540	-	-
Dist. Temp., 90% Point, °F, Max.	D86	640	-	-
Pour Point, °F, Max.	D97	20	-	-
Carbon Res. (10% Bot.), Wt %, Max.	D524	0.35	-	-
Ash, Wt %, Max.	D482	0.01	0.03	-
Trace Metals		See Note (a)		
Water & Sediment, Vol %, Max.	D1796	0.05	1.0	1.0
Sulfur, Wt %, Max.	D129	Legal	Legal	Legal

(a) For improved turbine life, the turbine user must make arrangements to assure that the fuel at the turbine fuel nozzle meets the requirements shown below. This might include transportation arrangements with the fuel supplier, particular care to on-site fuel storage and quality control procedures, and on-site cleanup procedures.

Trace Metals

Vanadium	D2787	0.5	0.5	(b)
Sodium Plus Potassium	D2788	0.5	0.5	(b)
Calcium	D2788	0.5	0.5	(b)
Lead	D2787	0.5	0.5	(b)

(b) Consult turbine manufacturer.

Table 4-2 - General Electric
Liquid Fuel Specifications

APPLICABILITY	PROPERTY	POINT OF APPLICABILITY (a)	ASTM TEST METHOD (c)	TRUE DISTILLATES (b)		ASH-BEARING FUELS (b)	
				LIGHT.	HEAVY	CRUDES AND BLENDED RESIDUAL FUELS	HEAVIER RESIDUAL FUELS
3.1 Gas Turbine Requirements	Kin. Viscosity, cSt, 100°F (37.8°C), min	Delivery	D445	.5 (d)	1.8	1.8	1.8
	Kin. Viscosity, cSt, 100°F (37.8°C), max(e)	Delivery	D445	5.8	30	160	900
	Kin. Viscosity, cSt, 210°F (98.9°C), max(e)	Delivery	D445	-	4	13	30
	Specific Gravity, 60°F (15.6°C), max	Delivery	D1298	Report	Report	.96	.96 (f)
	Flash Point, °F (°C), min (g)	Delivery	D93	Report	Report	Report	Report
	Distillation Temp. 90% Point, °F (°C) max	Delivery	D86	650 (338)	Report	-	-
	Pour Point, °F (°C), max	Delivery	D97	0 (-18) or 20 (7) below min. ambient	Report	Report	Report
	Carbon Residue, Wt. % (10% Bottoms) max.	Delivery	D524	.25	-	-	-
	Direct Pressure Atomization	Delivery	D524	1.0	1.0	1.0	-
	Carbon Residue, Wt. % (100% Sample) max.	Delivery	D524	-	-	Report	Report
	Air Atomization, Low Pressure	Delivery	D524	-	-	Report	Report
	Carbon Residue, Wt. % (100% Sample), Air Atomization, High Pressure	Delivery	D524	-	-	Report	Report
	Ash, ppm, max	Combustor	D482 (i)	50	50	Report	Report
	Trace Metal Contaminants, ppm, max (h)	Combustor	D482 (i)	50	50	Report	Report
	Sodium plus Potassium	Combustor	D482 (i)	1	1	1	1
	Lead	Combustor	D482 (i)	1	1	1	1
	Vanadium (untreated)	Combustor	D482 (i)	.5	.5	.5	.5
	Vanadium (treated 3/1 wt. ratio Mg/V)	Combustor	D482 (i)	-	-	100	500
	Calcium	Combustor	D482 (i)	2	2	10	10
	Other Trace Metals above 5ppm	Combustor	D482 (i)	Report	Report	Report	Report
	Filterable Dirt, mg/100ml, max	Delivery	D2276	4	10	Report	Report
	Water & Sediment, Vol. %, max.	Delivery	D1796	.1	.1	1.0	1.0
	Water Content, Vol. %, max.	Fuel Skid	D95	.1	.1	Report (j)	1.0
	Thermal Stability, Tube No., max.	Delivery	D1661	-	2	2	2
	Fuel Compatibility, Tube No., max. (50/50 mix with second fuel)	Delivery	D1661	-	2	2	2
	Cetane No., min (Diesel Engine Start Only)	Delivery	D975	40	-	-	-
	Sulfur, Wt. %, max	Delivery	D129	Report	Report	Report	Report
	Wax content, Wt %	Delivery	(i)	-	Report	Report	-
	Wax Melting Point, °F	Delivery	(i)	-	Report	Report	-
		Delivery	(i)	-	Report	Report	-
The specifications below apply only when specific environmental codes exist							
3.2 Environmental Code Related Requirements	Sulfur, Wt. %, max	Delivery	D129 (i)	Compliance to any applicable codes.			
	Nitrogen, Wt %, max	Delivery	(i)	Fuel-bound nitrogen may be limited to meet any applicable codes on total NO _x emission.			
	Hydrogen, Wt %, min	Delivery	(i)	Minimum hydrogen level may be necessary to meet any applicable stack plume opacity limits (k)			
	Ash plus Vanadium, ppm, max	Delivery	(i)	Ash plus vanadium content of ash-bearing fuels may be limited to meet applicable stack particulate emission codes. (l).			

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Notes to Table 4-2

- (a) The fuel properties specified refer to the fuel at different points in the overall system:
Delivery - fuel as delivered to the turbine site.
Fuel Skid - fuel at inlet of fuel skid at turbine
Combustor - fuel at turbine combustors
- (b) Typical fuels within each general type are discussed in Appendix A.
- (c) ASTM Book of Standards, Parts 23 and 24.
- (d) In the viscosity range of 0.5 cSt to 1.8 cSt, special fuel pumping equipment may be required.
- (e) The maximum allowable viscosity at the fuel nozzle is 20 cSt for high pressure air atomization and 10 cSt for low pressure air and direct pressure atomization. The fuel may have to be pre-heated to reach this viscosity, but in no instance shall it be heated above 275°F (135°C). (This maximum fuel temperature of 275°F is allowed only with residual fuels.) The viscosity of the fuel at initial light-off must be at or below 10 cSt.
- (f) A specific gravity of 0.96 is based on average fuel desalting capability with standard washing systems. Fuels with specific gravities greater than 0.96 may be desalted to the required minimum sodium plus potassium limits by using higher capability desalting equipment (with higher attendant cost) or by increasing the gravity difference between the fuel and wash water by blending the fuel with a compatible distillate.
- (g) The fuel must comply to all applicable codes for flash point.
- (h) A total ash less than 3 ppm is acceptable in place of trace metal analysis.
- (i) No standard reference tests exist; methods used should be mutually acceptable to General Electric and the user.
- (j) Water content of crude oils should be reduced to the lowest level practical consistent with capability of available fuel treatment equipment, to minimize the chance of corrosion of fuel system components. In no case shall the water content exceed 1.0 vol. %.
- (k) A minimum hydrogen content is set to limit smoke emissions where required by local codes; for example, for 10% maximum stack plume opacity, the minimum requirement is 12.0% for True Distillate Fuels with the proper fuel atomizing system. A minimum of 11.0% is desirable for Ash-Bearing Fuels, or 11.3% minimum when the carbon residue is greater than 3.5% (on 100% sample).
- (l) Local codes on total stack particulate emissions may set an upper limit on the sum of the ash (non-filterable) in the original fuel plus the vanadium content. The vanadium together with the required magnesium inhibitor may be a major contributor to total stack particulate emissions. In estimating these emissions for comparison with the code, all of the following sources may have to be considered: vanadium, additives, fuel ash and total sulfur in the fuel; non-combustible particulates in the inlet air; solids from any injected steam or water; and particles from incomplete fuel combustion. Where an estimate of stack particulate emissions is required, General Electric should be consulted.

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Table 4-3 - Fuel Specification
Westinghouse Gas Turbines

<u>PROPERTY</u>	<u>SPECIFICATION</u>
Flash Point	No Restriction (see text)
Reid Vapor Pressure	No Restriction (see text)
Pour Point	No Restriction (see text)
Viscosity	45-70 SSU for Ignition (see Text) 100 SSU for Combustion
Ramsbottom Carbon Residue	(see text)
Bottom Sediment and Water (BS&W)	(see text)
<u>Trace metal Content PPM (Wt)</u>	
Sodium plus potassium	≤ 0.5 without coatings >0.5 consult Westinghouse for coatings and/or treatment
Vanadium	≤ 0.5 untreated >0.5 consult Westinghouse for treatment
Lead	≤ 2.0
Calcium	≤ 10.0
Other Trace Metals	≤ 2.0
Sulfur %	≤ 0.5 with combined cycle and/or heat recovery units. No limit for Econopacs

Table 4-4

P&WA Fuel Specification
Distillate Fuel, Marine and Industrial Gas Turbine Engine

	ASTM Test Method	Limits
Distillation Temp., °F	D-86	
IBP		To be reported
10% Evap.		440 max.
20% Evap.		To be reported
50% Evap.		675 max.
90% Evap.		725 max.
Flash Point, °F	D-93	110 min. or legal
Pour Point, °F	D-97	To be reported
Cloud Point, °F	D-97	To be reported
Viscosity, Cs at 100°F	D-445	3.0 max.
Carb. Res. (on 10% Btms), Wt. %	D-524	0.15 max.
Sulfur, Wt. %	D-129	1.0 max.
Corrosion at 212°F, ASTM Code No.	D-130	1 max.
Ash, Wt. %	D-482	0.005 max.
Gravity, °API	D-287	To be reported
Neutrality	D-1093	Neutral
Net Ht. of Comb., BTU/lb	D-240 or D-2382	To be reported
Luminometer Number	D-1740	25 min.
High Temp. Stability	D-1660	
Pres. Change, in. Hg		12 max.
Preheater Dep. Code		2 max.
Sediment, mg/gal	D-2276	24 max.
Free Water Content, Vol. %	-	0.01 max.
Trace Metal Contaminants, ppm	-	
Vanadium		0.1
Sodium		0.1
Potassium		0.1
Calcium		0.1
Lead		0.1
Copper		0.02

Table 4-5 - Recommended Total Impurities Levels
Brown Boveri Turbomachinery, Inc.

	Na+K (ppm)	V (ppm)	Pb+Zn (ppm)	Ca (ppm)	S (%)	BS&W (%)	ASH# (ppm)	Atomic Nitrogen (ppm)
I. Distillate (#-GT, #2-GT)								
A. Optimum	0.5	0.5	1.0	2.0	Legal	0.05	20	(2)
B. Acceptable *	1.0	1.0	1.0	2.0	Legal	0.05	100	
II. Crude (#3-GT, #4-GT) (4)								
A. Peak Shaving Svc. **	2.0	1.5 ⁽¹⁾	5.0	10.0	Legal	1.0	(3)	(2)
B. Base Load ***	1.0	0.5 ⁽¹⁾	2.0	5.0	Legal	1.0		
III. Residual (#3-GT, #4-GT) (4)								
A. Peak Shaving Svc. **	2.0	1.5 ⁽¹⁾	5.0	10.0	Legal	1.0	(3)	(2)
B. Base Load ***	1.0	0.5 ⁽¹⁾	2.0	5.0	Legal	1.0		

* Acceptable on economic grounds, see Section III, para. F, page 7

** For meeting peak demands, turbine at base rating, 1000 hr/yr or less

*** For continuous operation (over 1000 hr/yr)

In fuel only

- (1) Fuel with up to 150 ppm V may be used with suitable inhibitor additives under conditions discussed in the text. Candidate fuels with vanadium contents above this level should be cleared by Brown Boveri Turbomachinery Engineering Department on an individual case basis.
- (2) Nitrogen contents of all candidate fuels should be reported to Brown Boveri Turbomachinery Engineering Department.
- (3) Ash contents of all candidate fuels should be reported to Brown Boveri Turbomachinery Engineering Dept.
- (4) The limits specified, with the exception of vanadium limits, are intended to apply to fuel after treatment.

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SECTION 5

ON-SITE FUEL PRETREATMENT

On-site treatment can be employed to upgrade quality to acceptable specifications for use in gas turbines.^{1,2,3,4,5,6} Such treatment(s) can permit the use of lower cost fuels by removing impurities which may have detrimental effects on gas turbines. When fuels do not meet quality standards, each turbine and its fuel are considered individually to determine if pretreatment is possible and, if so, for selection and design of a correct treatment system. Detrimental effects caused by impurities include:

- High temperature corrosion
- Ash deposition
- Fuel system fouling

Trace metal elements are the cause of high-temperature corrosion. They form compounds that melt on the gas turbine hot-gas path components, dissolve the protective oxide coatings and thereby leave the metal surfaces open to corrosion. Sodium, potassium, vanadium, and lead in conjunction with sulfur in the fuel are the prime causes of such high temperature corrosion.

In addition to trace metals, other impurities in the fuel may form ash deposits which gradually decrease the cross-sectional area of the gas path and thereby reduce the performance of the turbine. Presence of solid oxides, silicates, sulfides, and related compounds in the fuel are the principal cause for fouling of fuel system components.

Distillates, such as No. 2 diesel oil, are ideal gas turbine fuels and normally require only a minimum of on-site fuel preparation equipment. This would normally consist only of filtration to prevent entry of particulate matter into the gas turbine combustor with the fuel. In cases where excessive water may be present in the fuel, this must be removed by mechanical means. Excessive water can cause corrosion of fuel handling components and turbine malfunction.

On-site gas turbine fuel pretreatment other than simple filtration is normally confined to cases where heavy petroleum liquid fuels are used. These include crudes, heavier residual fuels, and blends of crude or residual with distillate. True distillate fuels do not normally require any special pretreatment other than to remove contaminants that may be introduced during transportation or storage. Use of residual and crude fuels for gas turbines is very limited in the United States because such fuels usually have a sulfur content which exceeds allowable limits. Therefore, on-site fuel treatment systems for such fuels are not common in the United States. However, such treatment systems are fairly common in other parts of the world where sulfur emission limits are less stringent because of the substantial economic advantage of using crude or residual fuels in conjunction with fuel treatment rather than using distillates fuel.

The common impurities in gas turbine fuels of primary interest are shown in Table 5-1 along with the typical limits, effect on turbine and the type of treatment normally used. There is no known economical technique for removing or providing inhibition of lead. Therefore, it is necessary to restrict gas turbine fuels to those containing less than 1 ppm. There is no known economical on-site method for removing sulfur or sulfur compounds. As discussed previously this has restricted the use of crude and residual fuels for gas turbines in the United States because these fuels normally contain levels of sulfur in excess of the levels permitted by emission rules.

The methods of on-site fuel treatment presently in use fall into three broad categories: (1) filtration, (2) fuel additives to inhibit the detrimental effects of impurities and (3) removal of impurities by water washing. Each of these is described below.

5.1 FILTRATION

Filtration is normally provided for all gas turbine fuel systems to remove particulate matter from the fuel which may be present in the fuel as produced or may be introduced during handling and storage. The most common contaminants that can be removed by adequate filtering include solid oxides, silicates, and related compounds. Presence of these particles will lead to clogging of fuel pumps, flow dividers, and the fuel nozzles in the turbine combustors.

There are many types of filtration systems used in gas turbine fuel systems. Most on-site heavy petroleum fuel systems contain several different stages of filtering. Strainers are provided between the fuel pump suctions and storage tanks. Where the strainer load is high, these can be of the motor driven self-cleaning type. These are usually followed by 50 and 100 mesh screens down-stream of the pump. Finally, just prior to the combustor, the fuel is filtered with 5 or 10 micron filters. For lighter liquid fuels, coalescing filters are often used to remove water containing salts. Where fuels contain a large amount of solid particulates, centrifuges can be employed to clean the fuel, thereby minimizing filter maintenance.

5.2 FUEL ADDITIVES

In practice, fuel additive treatment is used only for inhibition of vanadium in the fuel by addition of magnesium compounds. This has been found to be the most cost effective manner of dealing with high vanadium content. Vanadium occurs in petroleum fuels as an oil-soluble form which cannot be removed from the fuel by waterwashing or mechanical separation. The magnesium compounds arrest the corrosive characteristics of vanadium by forming high melting temperature ash composed of magnesium sulfate, magnesium oxide, and magnesium vanadates.

There are several types of magnesium additive systems in use for vanadium inhibition. A ratio of approximately three parts of magnesium to one part of vanadium is required. The general types of additives that are used are oil soluble (magnesium sulfonate and magnesium naphthenate), suspended (magnesium oxide and hydroxide), and water soluble (magnesium sulfate). Of these compounds, the easiest to use are the oil soluble compounds. They are simply metered into and mixed with the fuel. Capital equipment cost is minimal, but operating cost is high due to the high cost of these compounds. This approach is acceptable for relatively low vanadium levels or low fuel consumption levels.

Magnesium sulfate, commonly known as Epsom salts, is the lowest cost magnesium additive. However, this compound is supplied in crystalline form and must be dissolved in water prior to use. It is normally injected on a continuous basis as a water solution into the fuel line directly ahead of the turbine so that there is no chance of settling. For use on a batch basis, it must be emulsified into the fuel by use of an emulsifying agent.

Suspension type additives are concentrated stable suspensions of very finely divided magnesium oxide or magnesium hydroxide in the fuel oil. These concentrated suspensions disperse readily in the fuel to form uniform mixture and must be continuously mixed to prevent separation if stored for more than a limited time. These additives are the most concentrated and therefore result in the lowest cost for shipping and handling. The cost of these compounds on a magnesium content basis is somewhat more than magnesium sulfate and considerably less than the oil soluble compounds. However, the presence of fine solids in the fuel as a result of addition of these compounds present a risk of excessive abrasive wear on fuel pumps and flow dividers unless the particles are kept extremely small.

Silicone additives have been used to make gas turbine combustion ash drier, less dense, and more friable. Silicone has usually been used in conjunction with a magnesium additive. The reason for modifying the nature of the ash is to achieve less ash deposition in the hot-gas flow path and/or to produce an ash which is more readily removed by turbine cleaning.

5.3 WATER-WASHING

Water-washing has become an acceptable method of removing soluble trace metals from liquid gas turbine fuels (basically, sodium, potassium and calcium) to minimize high temperature corrosion, as well as their effect in the presence of sulfur.

There are 2 methods of water-washing, commonly referred to as "electrostatic precipitation" and "centrifuging". Both of these systems treat the fuel oil in an identical manner; however, using a different means of eventually separating wash water from the gas turbine fuel. In both cases, fuel is emulsified with water through the aid of a wetting agent in order to dissolve trace elements in the wash-water. In the case of the electrostatic precipitator, the fuel is separated from the aqueous phase by electro-coalescence after the water has dissolved soluble trace elements. The fuel is subsequently inhibited for vanadium presence before being burned in the gas turbine. In the case of the centrifuge, wash-water is removed from the fuel by mechanical means prior to sending the fuel to vanadium treatment and subsequent combustion in the gas turbine.

It is important to control viscosity and fuel temperature during water-washing process to assure high purification efficiency.

For highly contaminated fuels, several stages of water-washing may have to be employed and there are cases where, because of the fuel characteristics, water-washing using electrostatic precipitators followed by centrifuges have been employed. The exact method, of course, would be based on the analysis of the fuel being considered for gas turbine application.

Both the electrostatic precipitator and the centrifuge water-washing methods have additional side benefits; they provide additional filtration of the gas turbine fuel prior to combustion. The electrostatic unit is effective in removing extremely small particles, particularly those having a size less than 5 microns. The centrifuge, on the other hand, is more adaptable to removing the larger particle sizes. Hence, depending on the fuel characteristic, it is desirable in certain cases to combine the two systems to provide not only water-washing but also added filtration in order to eliminate the need for an elaborate filtration system. Figure 5-1 depicts a typical water wash separation system with chemical aid additions.

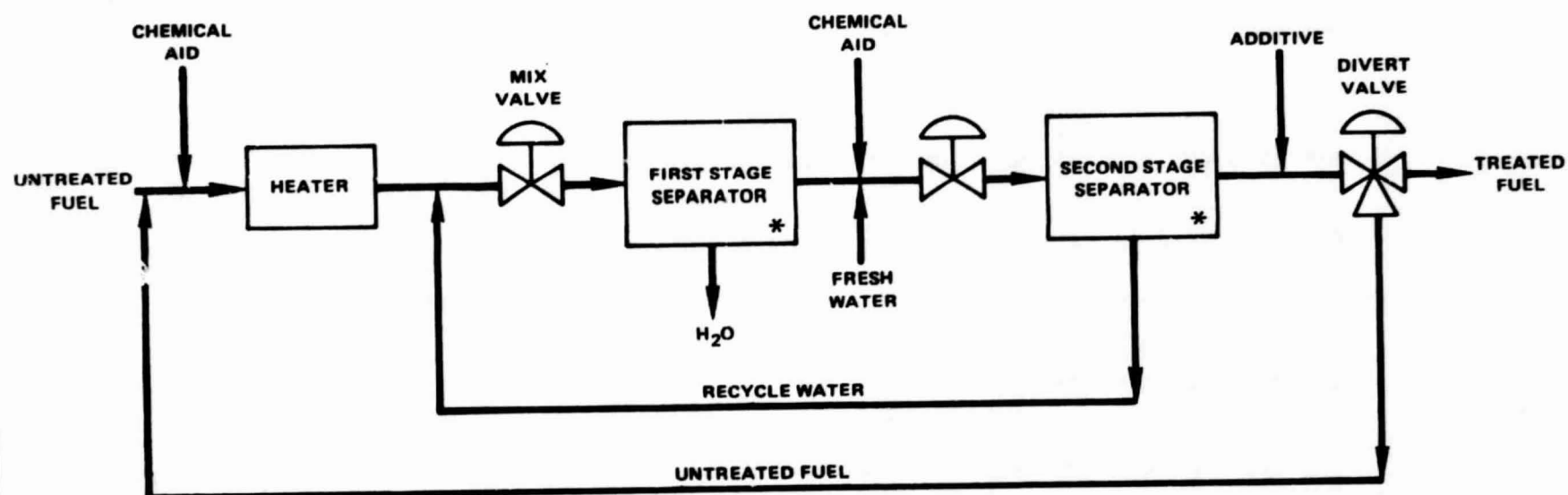
Because some of the modern gas turbine fuel systems require extremely low particulate content in the fuel, a water-wash arrangement using electrostatic precipitators and centrifuges is indicated, even though allowable trace elements are within accepted limits. This is because the typical 5-micron filter does not give adequate particulate removal performance.

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TABLE 5-1
GAS TURBINE FUEL IMPURITIES

IMPURITY	TYPICAL LIMITS	EFFECT ON TURBINE	TYPE OF ON-SITE TREATMENT
Particulate Matter	Note (1)	Fuel system fouling and erosion of gas path components	Filtration and centrifuging
Sodium plus Potassium	150 ppm	High temperature corrosion	Water washing of fuel
Calcium	10 ppm	Hard deposits	Water washing of fuel to a limited extent
Lead	1 ppm	High temperature corrosion	No known economical method
Vanadium	0.5 ppm	High temperature corrosion	Inhibited by addition of magnesium to the fuel
Sulphur	Note (2)	High temperature corrosion in the presence of sodium and potassium	No known economical on-site method
<p>Notes: (1) Limits on particulate matter are a function of the total for both the combustion air and the fuel. Limits on particulate matter are normally determined by air quality requirements rather than limits imposed by detrimental effects on the turbine.</p> <p>(2) Sulfur alone is not a problem with regard to its effects on turbine components. Sulfur limits are dictated by emission limits for SO₂.</p>			



* MAY BE EITHER ELECTROSTATIC PRECIPITER OR CENTRIFUGE

Figure 5-1 - Typical Flow Diagram of an Electrostatic System

SECTION 6

FUEL STORAGE AND BLENDING

Storage of raw syncrude liquids in nitrogen blanketed API cover roof tanks is required to prevent oxidation and/or degradation of the syncrude liquid. It has been found that chemical degradation occurs in polar asphaltene compounds of syncrude when exposed to the atmosphere. The blanketing material must be nitrogen or an equally inert material. The use of carbon dioxide as a blanketing gas has resulted in increased quantities of sludge formation indicating an objectionable reactivity.

The DOE Energy Technology Center, Bartlesville, Oklahoma, is sponsoring a series of studies on the subject of "Stability Characteristics of Hydrocarbon Fuels". Coal and oil shale derived synthetic fuels are included in the program. The first report, expected in two months, will include both theoretical and practical aspects. Preliminary results with syncrudes have shown that:

1. Thermal stability is often unsatisfactory.
2. There can be an interactive effect (synergism) between syncrude components which causes polymer (gum) formation, while each individual compound may be inert.
3. For nitrogen-containing fuels, stability was found to be related to particular nitrogen compounds rather than to the overall nitrogen content. Alkylated pyrroles have been found most active in fuel property degradation.
4. Stability can be improved by addition of antioxidant agents, by addition of specific additives tailored to the fuel composition (e.g. neutralizing the action of pyrroles if these are present), by re-refining of the fuel, or by hydrotreating.

In general, it is felt that appropriate treatments can create stable fuels. The degree of treatment depends on the energy and economic costs involved and on the

minimum degree of stability acceptable. Treatment selection will be dictated by a trade-off between these factors and will vary according to the specific fuel utilization and the corresponding logistics.

Blending of syncrude liquids can be significantly different from blending petroleum refinery liquids. This is due to the high aromatic content of syncrude refinery liquids even after hydrotreating. This introduces a degree of incompatibility when coal liquids are blended with paraffinic stocks. Such incompatibility could result in sludge formation and/or insoluble compounds being formed. The options are further hydrotreating to reduce aromatic content before blending or use of coal syncrude liquids with modified burner systems.

Blending of naphthas to gasoline would be the same as with now normal refinery practice.

SECTION 7

EMISSION SOURCES AND CONTROLS

7.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has carried out a considerable amount of work (directly, or indirectly through contractors¹ in the field of emissions from stationary gas turbines.¹ Most of the information presented in this section has been obtained from EPA; the major references are presented at the end of the section. Where appropriate for purposes of this literature survey summary, certain sections of the following presentation represent direct excerpts from the references cited; copies of published tables and figures are also presented for reference.

The pollutants emitted from gas turbines are those common to all combustion sources, NO_x , CH, CO, SO_2 , particulates, and visible emissions. The mass emissions from stationary gas turbines will differ depending on several variables such as turbine firing temperature, turbine pressure ratio, turbine load, combustor design, and atmospheric conditions. Table 7-1 shows typical visible, CO, SO_2 , and NO_x emissions for turbines of various sizes manufactured by several companies when fired with both natural gas and liquid fuels.¹ The table shows that for turbines operating at base load visible emissions are generally less than 10 percent opacity, NO_x emissions range from 0.94 lb/hr to 1578 lb/hr for turbines having outputs of 0.16 MW and 87.8 MW, respectively, and CO emissions range from 0 lb/hr to 47.2 lb/hr for turbines having outputs of 60 MW and 51.7 MW, respectively.

Sulfur dioxide emissions are a function of the efficiency of the gas turbine and the sulfur content of the fuel, since virtually all fuel sulfur is converted to oxide.

Unburned hydrocarbon emissions from gas turbines are due to vaporized unburned fuel or partially burned products which escape the combustion reaction

zone and are emitted in the exhaust. Since combustion efficiencies of gas turbines operating at base load normally exceed 99 percent, hydrocarbon emissions at base load are not substantial and may range from 1 to 5 ppm total hydrocarbons measured as methane or hexane (1 ppm is approximately equal to 3 lb/hr for a 30 MW turbine). Ambient hydrocarbon levels during many of these tests for hydrocarbon emissions were also measured as 1 - 5 ppm.

Particulate emissions from gas turbines consist of ash from the fuel, carbon particles and hydrocarbons resulting from incomplete combustion. Depending on the size of the turbine and the fuel burned, particulate emissions range from 1 lb/hr to over 40 lb/hr and vary from 0.002 gr/scf to 0.10 gr/scf. For example, particulate emissions from a turbine operating at 20 MW and burning natural gas were 4.8 lb/hr while those from a turbine operating at 52 MW and burning #2 oil were about 41 lb/hr. Somewhat higher levels of particulate emissions may result from gas turbines fired with crude or residual fuels.

Visible emissions or smoke emissions from gas turbines may be caused by only a small portion of the total particulate emissions since they are comprised of the extremely small and finely divided particulate matter. Various studies have indicated that the major contributor to visible emissions are the particulates consisting of low density agglomerates of carbon which are generally less than 1 micron in size and of the same order of magnitude as the wave length of visible light thus producing a greater visual effect than larger particulates. Table 7-1 shows that visible emissions from stationary gas turbines operating at base load are generally less than 10 percent opacity.

Nitrogen oxides are formed by the combination of nitrogen and oxygen in the combustion air ("thermal" NO_x) and by the combination of nitrogen in the fuel with oxygen from the combustion air ("organic" NO_x).

7.1 FACTORS AFFECTING EMISSIONS FROM STATIONARY GAS TURBINES

7.1.1 PARTICULATE AND VISIBLE EMISSIONS

Some fuels may form more smoke or visible emissions than others if compensatory design changes are not incorporated in the combustion system. The

paraffinic saturated fuels tend to "smoke" less than the aromatic or unsaturated fuels and this smoking tendency is related to the chemical bond energies necessary to completely consume the fuel. Fuel hydrogen content and residual carbon content also affect visible emissions. A reduction in hydrogen content or an increase in residual carbon, or both, can increase visible emissions. Figure 7-1 presents visible emissions versus the firing temperature of the gas turbine when burning an East Coast residual fuel.

Other factors which affect visible emissions are combustor design parameters which primarily relate to the fuel/air ratio and to the mixing of fuel and air. Carbon can be formed in the primary zone of the combustor if local areas of fuel rich mixture exist. Therefore, combustor designs which provide leaner fuel to air ratios (less fuel, more air), minimize the number of localized fuel rich areas, provide effective fuel atomization and mixing with air, and result in sufficient lean regions within the combustor for smoke burnout, are the most effective in decreasing the particulate load and thereby visible emissions.

7.1.2 HYDROCARBONS AND CARBONS MONOXIDE

Incomplete combustion is the principal cause of emissions of hydrocarbons (HC) and carbon monoxide (CO). Gas turbines are typically designed for optimum combustion efficiency in excess of 99% at full load. This efficiency, however, typically drops to the 90 to 95 percent range for operation at idle or low power conditions. Because of this drop, emissions of HC and CO from the turbines will be higher for turbine start-up and operation at low loads and will be a minimum at full load operations. Figure 7-2 shows HC emissions versus fuel to air ratio, and Figure 7-3 shows CO emissions versus firing temperature. Since fuel to air ratio and firing temperature are proportional to gas turbine load, Figures 7-2 and 7-3 demonstrate the trend for HC and CO emissions to increase with decreasing turbine load. This increase becomes exponential at low loads.

The low combustion efficiency (and, hence, higher HC and CO emissions) experienced in gas turbines operating at low loads is due to the poor burning conditions. Low combustion inlet air temperatures cause quenching to occur thus terminating combustion before completion, and the low fuel to air ratios (fuel lean combustion) result in lower burning intensity in the primary

zone of the combustor. The low fuel and air flows at low power operation result also in poor fuel atomization and distribution.

The specific ratio of HC and CO emissions from gas turbines operating at low power conditions (and, therefore, lower efficiency) also varies with specific design features of the engine combustor and fuel injection systems. The ratio of CO to HC emissions generally increases as the efficiency level increases. This is consistent with the chemical kinetics of combustion reactions which show that HC compounds are consumed faster than CO, with the result that, as gas turbine efficiency is increased, any remaining non-equilibrium products of combustion will tend to exist mainly as CO. The levels of CO and HC emissions from gas turbines with high compression ratios (ratio of compressor inlet air pressure to compressor outlet or combustor inlet pressure) are less than CO and HC emissions from turbines with lower compression ratios, because the increased combustor inlet temperatures and pressures due to higher engine compression ratios result in improved combustion efficiency at idle or low power conditions.

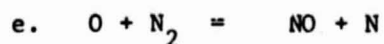
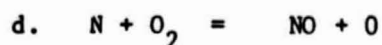
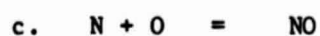
Another factor which may affect HC and CO emissions from a given engine is the type of fuel burned. These effects can be somewhat alleviated by proper design of the combustor to burn specific fuels. Figure 7-4 shows CO emissions versus load for a 26 MW gas turbine produced by Westinghouse Electric Corporation when burning a heavy distillate fuel, No. 2 distillate fuel, and natural gas. CO emissions when burning heavy distillate fuel are consistently above those when burning the other fuels. Figure 7-5 shows HC versus load for the same turbines and fuels; in this case no significant differences are observed.

7.1.3 NITROGEN OXIDES

Nitrogen oxides (essentially nitric oxide, NO) produced by combustion of fuels in stationary gas turbines are formed by the combination of nitrogen and oxygen in the combustion air ("thermal" NO_x) and by the combination of nitrogen in the fuel with oxygen from the combustion air ("organic" NO_x).

A. Thermal NO_x and the Variables Effecting its Formation

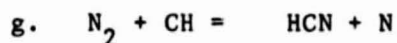
The NO_x formation mechanism by the combination of atmospheric nitrogen and oxygen (thermal NO_x) for fuel lean combustion in the combustor primary zone is commonly described and modeled using the Zeldovich mechanism which is described by the following equations:



The reactions were expanded by others to include an intermediate hydroxide molecule (OH) in the fuel rich region:



and to include the intermediate product of hydrogen cyanide (HCN) by combination of a nitrogen atom with a hydrocarbon molecule in the fuel rich combustion zone.



These reaction mechanisms are commonly used by the manufacturers of gas turbines in computer models to predict emissions from their conventional combustors which operate at, or near, stoichiometric combustion conditions. They are not valid for combustors which may be developed to operate at off-stoichiometric conditions (such as fuel rich combustion), thereby reducing NO_x emissions.

The Zeldovich equation for the formation rate of thermal nitric oxide (ppm/m sec) is:

$$i. \quad \frac{d X_{NO}}{dt} = k P^{0.5} X_{O_2}^{0.5} X_{N_2} T_f^{-1} e^{-122,000/T_f} \left(1 - \frac{X_{NO}}{X_{NO_e}} \right)^2$$

where:

K = constant of formation

P = combustor pressure

T_f = flame temperature

X = the volumetric fraction of the substance (i.e., O₂; N₂; NO)

(X_{NO_e}) = nitric oxide equilibrium concentration

Equation (i) shows that the thermal nitric oxide formation rate is extremely sensitive to the flame temperature, increasing exponentially with increases in flame temperature. From this equation, we can also observe that the formation of NO varies with the square root function of the combustion pressure and with the N₂, O₂, and NO concentration. As the concentration of nitric oxide reaches its equilibrium value, the bracketed figure (equation i) becomes zero and thus the nitric oxide formation rate becomes zero.

The thermochemical equilibrium quantities of NO that can be generated depend strongly on the combustion temperature levels and on the availability of oxygen. Thus, the equilibrium quantities of NO produced increase rapidly with increases in combustor inlet temperature and as the fuel to air equivalence ratio approaches values of 0.8 to 1.0. Fortunately, the quantities of NO_x emissions generated by gas turbines are limited by the short residence times of the hot combustion gases within the engine combustor and by the rapid quenching of these gases with the dilution air. Therefore, very high combustion

efficiencies can be attained without generating the thermochemical equilibrium quantities of NO. Some typical nitric oxide formation rate data for gas turbines are shown in Figure 7-6, which shows that NO formation rates increase as combustor inlet temperature and pressure increase and that operation of the combustion process at equivalence ratios less than or greater than stoichiometric (equivalence ratio = 1.0) will result in reduced formation of NO.

There have been many attempts to develop correlations between NO_x emissions and the many variables (such as temperature, pressure, humidity, residence time, air to fuel ratio, etc.) which affect these emissions. During the process of developing standards of performance for stationary gas turbines, several correlations were provided to EPA and these are summarized in Table 7-2. Equations 1 and 2 in the table were submitted with the recommendation that they be used to correct emissions from gas turbines, regardless of manufacturer, to a common set of reference conditions. Manufacturers of gas turbines, however, believed that these equations were not applicable to their engines and stated that, in their opinion, individual equations would probably have to be developed for each gas turbine and combustor combination. Equations 3, 4 and 5 of Table 7-2 were submitted with additional data to show their applicability and accuracy when applied to engines of the specific manufacturer. Data presented by the manufacturers indicate that equation 3 can correct emissions to an accuracy of ± 7.5 percent, equation 5 and equations developed by Detroit Diesel Allison Division of General Motors also have been shown to predict emissions very accurately for specific machines. Despite their obvious differences, the equations reported in the literature and those shown in Table 7-2 have some common characteristics. These common characteristics are summarized as follows:

1. Most pressure dependence data supports the conclusion that the correction factor for the effect of pressure on NO_x emissions is of the form:

$$\frac{\text{NO}_x + \text{NO}_x \text{ OBS}}{P_3 \text{ observed}} = \frac{P_3 \text{ reference}}{0.5}$$

Where P_3 equals the compressor discharge or regenerator discharge pressure.

2. Most humidity dependence data supports the conclusion that the correction factor for the effect of humidity on NO_x emissions is of the form:

$$\text{NO}_x = (\text{NO}_x \text{ OBS})^{e^{K(\text{Hobs} - \text{Href})}}$$

Where K, a dimensionless constant, has been shown to be equal to 22 ± 8 . $K=19$ is the value most commonly chosen although some manufacturers have developed a specific constant for their machine. Ideally, the development of a specific constant for each machine is the better approach since it has been analytically calculated that the correction factor for humidity will vary with compression ratio, which is a function of machine design.

B. Organic NO_x and Variables Affecting its Formation

Organic NO_x is formed during combustion by the chemical combination of the nitrogen atoms contained in the fuel molecule with oxygen from the air; the exact mechanism of NO_x formation is not known. Generally, organic NO_x is only a problem when burning residual oils, blends, some crude oils, or heavy distillate fuels which have high nitrogen contents. Most light distillate fuels have less than 0.015 percent by weight nitrogen, and crude oils generally have less than 0.2 percent, while residual oils can go as high as 2 percent.

The maximum organic NO_x that will be produced when burning a given fuel in a gas turbine, assuming all fuel bound nitrogen is converted, may be calculated from the following equation:

$$\text{NO (ppm by volume)} = \frac{N_f \times W_f}{W_f + W_w + W_a} \times \frac{30}{14} \times \frac{28.95}{30} \times 10^6,$$

where N_f = fuel-bound nitrogen, percent by weight (expressed as a decimal)

W_f = combustor air flow rate, lbs/sec

W_w = water injection flow rate, lbs/sec

30 = molecular weight of NO

29.95 = average molecular weight of combustor exhaust gas

14 = atomic weight of nitrogen

This simplifies to:

$$\text{NO} = \frac{N_f \times W_f/W_a \times 2.0679 \times 10^6}{(1 + W_f/W_a + W_w/W_a)} \quad (\text{ppm by volume})$$

In their experiments with a combustor from the MS 5000 series gas turbine, General Electric Corporation found that the actual conversion of fuel bound nitrogen varies with the nitrogen content of the fuel and to a lesser extent with the fuel to air ratio at which the gas turbine was operated. They therefore performed experiments using the MS 5000 series combustor operating at a constant fuel to air ratio of 0.021 to develop the curve shown in Figure 7-7. This curve shows that the percentage of fuel bound nitrogen converted to NO_x decreases as the fuel nitrogen content increases. Using this curve and the equation given above for calculating the NO_x contribution assuming 100 percent conversion of the fuel nitrogen, one can then calculate the NO_x contribution of the fuel to the total NO_x emissions from the MS 5000 gas turbine operating at a 0.021 fuel to air ratio.

The general applicability of the curve shown in Figure 7-7 to combustors with different designs has not been shown. For example, data developed by Westinghouse show that for a fuel with 0.79 percent bound nitrogen the yield factor was about 20 to 30 percent compared to the 40 to 50 percent shown for the General Electric turbine (both machines were operated at firing temperatures in the 1800°F range); furthermore, the percent conversion of fuel bound nitrogen decreased with increased firing temperature, while G. E. data indicate that the percent conversion increases with increasing firing temperature. It has also been reported that the yield of NO_x from bound nitrogen in the fuel is less for fuel rich combustion than for combustion with leaner fuel mixtures.

C. The Effects on NO_x Emissions of Burning Various Fuels in Stationary Gas Turbines

Burning natural gas instead of number 2 distillate in a given gas turbine can result in reducing NO_x emissions by as much as 50 percent. This has been theorized to occur because the combustion of liquid fuel droplets proceeds in the reaction zone at fuel to air ratios which result in localized peak flame temperatures (which are conducive to greater NO_x formation) while the combustion of the natural gas occurs at lower, more uniform temperatures. No significant difference in NO_x emissions for gas turbines firing heavy distillate, number 2 distillate, or even crude oil was observed.

A limited number of tests have been carried out using synthetic fuels. EPA tests carried out during their "Rich Burn - Quick Quench" program, using synthetic fuels of properties listed in Table 7-3, showed, as expected, NO_x emissions proportional to the fuel nitrogen content (Figures 7-8, 9, 10), although the combustor design achieved low emissions for all fuels at specific fuel/air ratios.

7.2 EMISSION CONTROL PROCEDURES

7.2.1 PARTICULATE EMISSIONS

Particulate emissions from gas turbines consist of ash from the fuel, carbon particles and hydrocarbons resulting from incomplete combustion. Fuels containing high ash and vanadium contents will result in higher particulate emission rates than light distillate fuels or natural gas. Magnesium, manganese and barium inhibitors added to liquid fuels to retard vanadium corrosion of the turbine components will also increase particulate emissions. Particulates are emitted from gas turbines at low levels, varying from 0.002 gr/scf to 0.10 gr/scf and exhaust gas volumes ranging from 166,206 scfm to 460.167 scfm for turbines operating at base loads of 12 and 44 megawatts, respectively.

Particulate emissions may be decreased by burning natural gas or low ash fuels and by combustor modifications which provide more complete combustion of hydrocarbons and carbonaceous particles. The only known application of a

particulate control device for gas turbines has been the installation of a packed bed scrubber on several jet-engine tests cells at a naval air station. This scrubber reportedly reduced particulate emissions from uncontrolled levels ranging from about 0.008 gr/scf to 0.015 gr/scf, depending on engine operating mode, to controlled levels ranging from 0.001 gr/scf to 0.005 gr/scf. Opacity after the scrubber was generally less than 10%. A jet engine test cell is not typical of a stationary gas turbine installation. Because a jet engine operates in different modes, including an afterburner mode, opacities vary from 0 to 80 percent, whereas a typical stationary gas turbine will operate with opacities generally less than 20 percent.

Visible emissions are related to particulate emissions; therefore, procedures achieving a reduction in particulate emissions from stationary gas turbines can also reduce visible emissions. Visible emissions can also be reduced by burning fuels with high hydrogen contents. Another method for reducing visible emissions is to use fuel additives, such as soluble compounds of manganese, barium, lead, iron and others. The actual mechanism by which these additives reduce visible emissions is unknown and somewhat controversial. Major reductions in visible emissions have been achieved through combustor redesign. The design of low visible emission combustors involves providing more effective fuel and air mixing in the primary zone and leaner fuel-to-air mixtures.

7.2.2 SO₂ EMISSIONS

SO₂ emissions from gas turbines are strictly a function of the fuel sulfur content and virtually all fuel sulfur is converted to SO₂. The only technique now used to control SO₂ emissions from gas turbines is to burn low sulfur fuels. Stack gas scrubbing for SO₂ removal has not been applied to gas turbines primarily because it is less costly to desulfurize the fuel. Relative costs will be presented in later phases of the study.

7.2.3 HYDROCARBON AND CARBON MONOXIDE EMISSIONS

Hydrocarbon and carbon monoxide emissions from conventional gas turbines are low at full load operation and increase asymptotically as turbine loads decrease. Most existing turbines are designed for maximum efficiency at

full load operation with efficiency dropping to 90-95 percent at low load operation. It is generally accepted as a "rule of thumb" that, for large gas turbines, a 1 percent decrease in turbine efficiency corresponds to 300 ppm of CO emissions.

HC emissions also increase with decreasing combustion efficiency. Most gas turbines, regardless of size, have HC emissions generally less than 20 ppm when operated at or near full load. Vaporized hydrocarbons and any partially oxidized hydrocarbons are consumed during combustion much more rapidly than CO and thus the major product of inefficiency is expected to be CO. This is demonstrated by data from an Airesearch GTC 85-90 gas turbine, as shown in Table 7-4.

The control of HC and CO emissions is primarily a function of fuel injection and atomization and fuel-air mixing. Decreased HC and CO emissions are therefore accomplished by combustor and fuel injection modifications which promote better fuel atomization and fuel and air mixing. They can also be obtained by controlling the fuel to air ratios and the residence time at temperature, as necessary, to provide combustion of the HC's in the primary zone of the combustor and combustion of the CO in the primary and intermediate zones of the combustor.

7.2.4 NO_x EMISSIONS

Nitrogen oxides produced by combustion of fuels in stationary gas turbines are formed by the combination of nitrogen and oxygen in the combustion air ("thermal NO_x") and from the combination of nitrogen in the fuel with oxygen from the combustion air ("organic NO_x").

It is generally recognized that there are four basic techniques to reduce the formation of thermal NO_x. These are:

1. Reduce the combustion pressure.
2. Decrease the peak flame temperatures in the combustor reaction zone.

3. Reduce the effective residence time during which the combustion gases remain at elevated temperatures.
4. Control the amounts of nitrogen and oxygen available for the production of NO_x .

No specific procedures, on the other hand, are available for the reduction of organic NO_x , except for removal of nitrogen from the fuel prior to combustion.

A. Control by Water or Steam Injection (Wet Technique)

The formation of thermal NO_x is extremely sensitive to flame temperature, increasing exponentially with increases in flame temperatures. Wet control techniques involve the injection of water or steam into the combustion process. The injected fluid provides a heat sink which absorbs some of the heat of reaction, thereby reducing peak combustion temperatures and the rate of NO_x formation.

The degree of NO_x reduction achieved for a given turbine depends on the rate and method of introducing the water. In experiments to maximize effectiveness, manufacturers have found that direct injection of atomized water into the primary zone of the combustor is best. The effectiveness of wet control techniques in reducing NO_x emissions is illustrated in Figure 7-11 where reductions of NO_x emissions in excess of 80 percent are shown. The band in the figure is a compilation of information provided by three major manufacturers of gas turbines, with the spread being due primarily to differences in combustor design, type of fuel used and method of water or steam injection; data points superimposed on the band represent the results of tests by EPA, operators of gas turbines, and other manufactures. Only minor differences have been found between water and steam injection concerning the effectiveness of NO_x reduction; however, water injection reduces gas turbine efficiency by about one percent for a water to fuel ratio of one, while steam injection at the same water to fuel ratio results in about a one percent increase in efficiency.

To reduce corrosion of the gas turbine components, only high purity water must be used for long-term water injection. The amount and quality of water injected into any turbine will vary from manufacturer to manufacturer

and from model to model produced by a company. Water treatment requirements will also vary depending on the fuel burned by the turbine, since manufacturers commonly specify the combined total quantity of elements in fuel, water, and air which must not be exceeded. Table 7-5 summarizes typical water quality specifications for gas turbines and compares them to boiler feed water requirements. Obviously the boiler feed water requirements are more stringent than those for the water injected into gas turbines. Utilities, therefore, commonly use equivalent water purification systems. Figure 7-11 shows that a 70 to 90 percent reduction in NO_x emissions can be obtained with a 1.0 water/fuel ratio. This amount of water represents about 5 percent of the consumptive water use of a comparable steam boiler.

The data reported in the literature are contradictory regarding the effect of water or steam injection on the emissions of particulates, CO and HC. Data concerning the effect of water injection on the conversion of fuel bound nitrogen are also scarce. General Electric has performed some very limited tests on a combustor rig using "nitrogen doped" fuels and by using this data in conjunction with some field test data have extrapolated the results to predict NO_x emissions from an MS-7001C simple cycle turbine burning fuels with different nitrogen contents, as shown in Figure 7-12. The curves presented in the figure represent total NO_x emissions (thermally formed NO_x plus organic NO_x). Looking at the curve for the 0.5 percent nitrogen fuel, one can observe that beyond a water to fuel ratio of about 1.2 to 1.3, the injection of additional water results in increases in emissions of NO_x . This would indicate that, beyond certain high rates of water injections, an increased yield of organic NO_x may result. These water injection rates, however, are substantially greater than would commonly be used for NO_x control, since a 1.0 water/fuel ratio will provide 70 to 90 percent reduction in thermal NO_x . Also, some of the water injection rates shown in Figure 7-12 would exceed the levels considered as a maximum for an operating gas turbine because the flame would be extinguished.

B. Dry Control Techniques

Dry control techniques for reducing emissions of NO_x from gas turbines are defined as those techniques which use operational or design modifications rather than water or steam injection; proper designs using these dry

techniques do not appear to affect gas turbine efficiency. However, because of the large changes in combustor environment between low power and high power operation of gas turbines and because of differences in the mechanisms of pollutant formation, combustor modifications which reduce CO and HC emissions at low gas turbine loads may increase NO_x emissions at high loads.

For conventional gas turbine combustors, it has been demonstrated that CO and NO_x emissions can be traded off against each other by changes in operating conditions or air flow distribution. Emission data obtained from tests of many gas turbine engines show that this trade-off will generally fall within the band illustrated in Figure 7-13. The use of variable geometry to control average temperature levels by controlling combustor air distribution would result in a trade-off of CO and NO_x emissions by shifting the emissions performance point either up or down the characteristic combustor performance line. An undesirable feature of this trade-off is that it merely trades one pollutant for another. Reductions of both pollutants (CO and NO_x) will require new combustor designs which either shift the CO - NO_x curve to the left as shown in Figure 7-13 or change the CO - NO_x characteristic trade-off curve.

Combustor designs utilizing dry control techniques to retard the formation of thermal NO_x usually operate on the following parameters:

- a. the reaction flame temperature
- b. residence time of the gases at temperature
- c. the amounts of oxygen available for conversion to NO_x
- d. atomization and vaporization of the fuel
- e. mixing of the fuel and air

The combustor design modifications applied involve mainly the following techniques:

- a. air staging and redistribution
- b. fuel vaporization
- c. fuel staging
- d. two stage combustion and off stoichiometric combustion
- e. premixing of the air and fuel prior to introduction to the combustion chamber
- f. variable combustor geometry
- g. exhaust gas recirculation

- h. catalytic combustion
- i. external combustion in a larger combustion chamber(s) where the combustion conditions can be more easily controlled than in a conventional gas turbine combustor.

The dry control techniques listed above have been applied individually or in combination by gas turbine manufacturers to reduce NO_x emissions with concurrent reduction in CO emissions. Many techniques have been researched in combustor rig tests while some have been applied in varying degrees to production engines. Much of the design information on the application of dry techniques to turbines by specific manufacturers is of a proprietary nature and cannot be divulged. In addition, where the data shown are from combustor rig tests, substantial effort may be required to incorporate such design changes into a production engine. The amount of further development work required will depend to some extent on whether "full size" combustors were used in the rig tests and on the sophistication of the simulation of actual combustor inlet conditions and of engine conditions such as the flow configuration and distribution downstream of the combustor. Durability and life tests under full engine operating conditions will also have to be demonstrated.

Many dry control techniques have been found effective. The use of advanced fuel injection methods such as airblast fuel atomization was shown to reduce NO_x emissions by 10 to 15 percent when compared to the more conventional fuel injection methods, while rapid introduction of dilution air to reduce the dwell time of the combustion gases at high temperatures resulted in a 30 percent reduction in NO_x emissions.

Reduced levels of NO_x emissions may be obtained by operating with much leaner or much richer average primary zone fuel/air ratios than stoichiometric. Experimental results for tests performed at Westinghouse on a standard gas turbine combustor using Number 2 oil with successive modifications to reduce residence time, lean the primary zone (increased air to fuel ratio) with reduced residence time, and use a very lean primary zone with reduced residence time, are shown in Figure 7-14. The curves demonstrate a maximum 40 percent reduction in NO_x emissions for the modified combustor as compared to the production combustor.

Results of research and development tests performed by Westinghouse on a one-half scale combustor without and with simulated exhaust gas recirculation burning Number 2 oil are shown in Figure 7-15: a 38 percent reduction in NO_x emissions was accomplished.

The NASA-Lewis Research Center has sponsored a number of projects as part of their "clean combustor" program to demonstrate practical combustor technology for the reduction of pollutants in future generation aircraft turbines. Within this program, Solar tested two basic combustor modifications, the vortex airblast combustor and the jet induced circulation combustor. Both concepts utilized lean primary zones, prevaporization of the fuel, and premixing of the air and fuel: reductions of NO_x emissions ranging up to 94% were obtained. General Electric performed rig tests of four basic full scale combustor design configurations, namely a single annular lean dome combustor, a double annular lean dome combustor, a radial/axial staged combustor and the NASA swirl-can combustor. All concepts featured increased air flow; the lean dome double annular combustor and the radial/axial combustor used airblast fuel injection, where a portion of the compressor discharge air is utilized to atomize the fuel and provide better fuel and air mixing. The NASA swirl-can combustor consists of a modular array of carburating swirl cans, each with an axial air swirler and a stabilizing plate. Each module is designed to premix the fuel with the air in the carburetor, swirl the fuel-air mixture, stabilize combustion in the swirl can wake and provide mixing areas between the bypass air through the swirl can array and the hot gases in the wake of the swirl can modules. With this configuration, fuel staging was investigated by controlling fuel flows to the various modules. NO_x emissions versus fuel-to-air ratio for a production combustor and the best configuration of each major design approach are shown in Figure 7-15. The radial/axial configuration resulted in the greatest reduction (60 percent) of NO_x emissions. The Pratt and Whitney Aircraft Group performed rig tests of three basic full scale combustor design concepts, the swirl-can combustor, the staged premix combustor, and the swirl vorbix combustor. The staged premix combustor consists of a primary or low power burner and a secondary high power burner with each burner having its own fuel injection system and premixing passage. The swirl vorbix combustor employs two burning zones: the pilot combustion zone only is fueled during low power conditions, with both burners used for high power conditions. NO_x reductions ranged up to 61 percent, with the swirl vorbix configuration exhibiting the greatest potential.

Pratt and Whitney performed for EPA during the period December 1975 - November 1979 an exploratory development program to identify, evaluate and demonstrate alternative combustor design concepts for significantly reducing the production of NO_x in stationary gas turbine engines.² The investigations were directed toward dry combustion control techniques suitable for use in a 25 megawatt (nominal) engine. Program goals were 50 ppmv NO_x (at 15% O_2) for non-nitrogenous fuels, and 100 ppmv NO_x (at 15% O_2) for fuels containing 0.5% nitrogen by weight. The goal for CO was 100 ppmv (at 15% O_2).

The first phase of the program consisted of an analytical investigation of combustion concepts considered to have potential for reducing the production of NO_x . In the second phase of work, a number of promising low NO_x production concepts were bench-tested to select the best candidate for implementation into the design of a full-scale, 25-megawatt-size, utility gas turbine engine combustor.

Based on this assessment, the "Rich Burn/Quick Quench" concept was selected for implementation into the design of a full-scale (25 megawatt engine size) gas turbine combustor. This concept (Figure 7-17) showed significant potential for application in stationary gas turbine engines, and was capable of meeting or exceeding all program exhaust emission goals.

Two configurations of the full-scale prototype combustor were designed and constructed. The first provided a primary zone residence time about as great as that utilized in the bench-scale combustor, but greater than that available in a representative 25 megawatt engine having on-board (in-line) burner cans. The second configuration was shorter in length, meeting the basic envelope requirements of the representative engine. Tests of the two configurations were conducted to verify proper implementation of the design concept, and to demonstrate the exhaust emission characteristics attainable in the full-scale design.

The test results were highly positive, showing that the Rich Burn/Quick Quench concept can produce substantial reductions in NO_x for both nitrogenous and non nitrogenous petroleum distillate fuels. Operation of the

prototype combustor on heavy fuels (coal-derived, shale-derived or petroleum residual fuel) also showed substantial reductions in NO_x when these fuels were fired. The properties of the fuels are presented in Table 7-3, while the NO_x , CO and HC emissions measured are shown in Figures 7-8, 9, 10 and in Table 7-6 (NO_x only). According to recent information received by personal communication, it is believed that fuel nitrogen contents up to 1.5% could meet the gas turbine NO_x emissions standards when fired with this experimental combustor.

All the program exhaust emission goals were met. Comparison of the general emission characteristics to those obtained earlier for the bench-scale combustor showed good agreement and indicated the same general dependence of NO_x concentrations on primary zone residence time. Extrapolation of the results to greater values of residence time indicates that further substantial reductions in NO_x can be achieved given increased combustor length. A second major implication of the test results was that the Rich Burn/Quick Quench concept may be directly applicable to heavy fuels. Having demonstrated substantial reductions in the quantities of NO_x formed due to fuel-bound nitrogen (commonly present in coal-derived and shale-derived feedstocks), the Rich Burn/Quick Quench concept may also overcome a second difficulty, lack of fuel volatility, because, under fuel-rich burning conditions, NO_x formed initially due to heterogeneous burning of nonvolatile droplets may reduce to nitrogen.

C. Catalytically Supported Thermal Combustion

Catalytically supported thermal combustion is an emerging and promising concept for the reduction of NO_x , CO and HC emissions from gas turbines. In the catalytic combustor, fuel and air are premixed prior to introduction to the catalyst core where the reaction begins, and combustion is completed at reaction temperatures below 2800°F , thereby avoiding much of the thermal nitrogen fixation. For comparison, the combustor axial temperature gradients for conventional, lean premix and catalytic combustor concepts are shown schematically in Figure 7-18.

The validity of the catalytic combustion concept has been demonstrated in a series of tests performed by Westinghouse in collaboration with Engelhard Industries. The catalytic combustor, as compared to the conventional

combustor, reduced NO_x emissions by more than 98 and 89 percent when burning distillate oil and coal gas, respectively, with concurrent reductions in CO and HC emissions. These reductions were accomplished with the catalytic combustor actually operating at a higher outlet temperature than the conventional combustor. Similar low emissions levels from catalytic combustion have been verified and reported in tests by Detroit Diesel Allison, NASA Lewis Research Center, and the Air Force Aero Propulsion Laboratory.

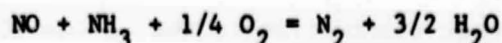
The catalytic combustion procedure was found ineffective in tests using No. 2 diesel oil doped with 1 percent of pyridine; for these fuels, the conversion of fuel bound nitrogen to NO_x was in the range of 70 to 90 percent. Engelhard has been studying improved catalysts to reduce conversion of fuel nitrogen to NO_x .

Although the results show that catalytically supported thermal combustion is a feasible concept for reduction of emissions from gas turbines, there are still some areas where additional research is required before a production gas turbine using catalytic combustion is a reality. Some of these are:

- a. The start-up problem - The catalytic combustor must reach a certain operating temperature, depending on fuel type, for ignition and continued combustion.
- b. Variable geometry will be required to operate the catalytic system over the full operating range of a gas turbine.
- c. The life of the catalyst and performance over this time period must be determined. Engelhard reports that catalysts in rig tests have demonstrated 1000 hours of operation without degradation in performance. Many stationary gas turbines operate 8000 hours per year.
- d. Maintainability and reliability must be demonstrated in a full turbine.

D. Reduction of NO_x in the Flue Gas

NO_x control can also be achieved by post-combustion treatment of the flue gas with ammonia, with or without catalysts.³ It is believed that oxygen participates in the reaction as follows:⁴



Uncatalyzed reaction with ammonia is used in the Exxon Thermal DeNO_x process, which has been applied for NO_x control in boilers and furnaces.⁶ In this process, ammonia is injected into the flue gas at a temperature range from 1140°K (1600°F) to 1250°K (1800°F); there it reduces NO by a homogeneous gas phase reaction. KVB, Inc., which tested this process, reported that use of ammonia at a rate equimolar to the flue gas NO_x concentration reduced NO_x emissions to 100 ppm (at 3 percent O₂) from a baseline level of 270 ppm. According to Exxon Research and Engineering, reductions of NO_x up to 70% are possible. Selective reduction in the presence of oxygen is highly temperature sensitive, but addition of small amount of hydrogen controls temperature for optimum results (Figures 7-18, 19, 20).

Hitachi (Japan) has developed catalysts resistant to SO₂ poisoning^{4,5} which can reduce NO_x to nitrogen by reaction with ammonia in the presence of oxygen in a temperature range of 200 to 400°C (Figures 7-21, 22). The exact catalyst composition is proprietary, but use of mixtures of refractory metal oxides of group IV elements (70-98 atom percent) and transition metal oxides has been reported. NO_x removal rates ranging up to 90 percent are claimed. A similar process, using non-noble metal catalysts, is the "Kleenaire Denox" system of the Nergas Corporation (Lafayette, Louisiana), which has been applied mainly to NO_x and CO removal from 500 to 2000 horsepower stationary hydrocarbon-fueled engines used by the petrochemical industry.

E. Other Approaches

A control alternative for the abatement of organic NO_x emissions in gas turbines is the removal of nitrogen from the fuel prior to combus-

tion. The cost of this alternative has been estimated by EPA⁷ in September 1979 at \$2-\$3 per barrel, an excessive economic penalty. Worth of consideration, however, could be the partial removal of nitrogen from the fuels, down to approximately 1.5 percent nitrogen, where dry control techniques (such as the "Rich Burn/Quick Quench" approach) become effective.

Another alternative is the deliberate maximizing of NO_x formation by maintaining high reaction temperatures, followed by the extraction of NO_x from the flue gas, for use as a chemical feedstock for the production of nitric acid. This possibility has been considered for the magnetohydrodynamic (MHD) power generation process⁸, where NO_x emissions as high as 4800 ppm can be reached. NO_x can be scrubbed out by sulfuric acid and converted to nitric acid using the Mitsui wet process. It was found, however, that this process was not cost effective when compared with NO_x control by combustion modification, due to higher capital and operating costs.

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Table 7-1
Visible, CO, NO_x, SO₂ Emissions from Stationary Gas
Turbines Produced by Six Manufacturers

Turbine	Manufacturer & Engine Model	Cycle Type	Fuel	Rated Base Load Power Output (MW)	Rated Heat Rate (Btu/MW-Hr)	Plasma Specificity (g)	NO _x				CO				Fuel Sulfur (wt %)	SO ₂		
							ppm @ 15% O ₂	g/MW	g/MW-Hr	g/sec	ppm @ 15% O ₂	g/MW	g/MW-Hr	g/sec		g/MW	g/MW-Hr	g/sec
SANDRETT-AIRESEARCH																		
1	GTG 85-90	S.C.	JET A	0.158 (0.150)	23,854	< 10	55	0.94	6.25	0.12	321	3.3	22.18	0.42	0.01	0.039	0.26	0.005
2	831 - 800		N.B.	0.51 (0.46)	15,742	< 10	109	3.69	7.37	0.47	7	0.15	0.29	0.02	0	0	0	0
							149	4.76	10.27	0.60	21	0.41	0.89	0.05	0.01	0.09	0.17	0.01
															0.1	0.88	0.71	0.11
SOLAR																		
3	Saturn	S.C.	N.B. Kerosene	0.8	15,680	<10	51	2.64	3.30	0.33	68	2.13	2.65	0.27	0	0	0	0
						>10	69	4.03	5.04	0.51	163	5.76	7.20	0.73	0.01	0.17	0.14	0.02
4	Centaur	S.C.	N.B. Kerosene	2.5	13,947	< 10	39	12.48	4.99	1.57	68	5.79	2.32	0.73	0	0	0	0
						>10	86	13.75	5.50	1.73	126	12.23	4.89	1.54	0.01	0.38	0.15	0.05
															0.1	3.79	1.52	0.48
DETROIT DIESEL ALLISON																		
5	404 - 3	R.C.	N.B. DF-2	0.20	11,300	2	113	1.61	6.15	2.02	70	0.60	2.30	0.08	0	0	0	0
						2	209	2.98	11.40	0.38	149	1.30	4.97	0.16	0.1	0.25	1.23	0.03
															0.3	0.74	3.69	0.09
															0.5	1.23	6.14	0.15
6	501K 13	S.C.	N.B.	2.5	12,530	1	99	16.09	5.74	2.10	11	1.17	0.40	0.15	0	0	0	0
7	501K 15	S.C.	DF-1			7	125	20.67	7.10	2.60	57	5.77	1.98	0.73	0.1	3.51	1.41	0.44
															0.3	10.54	4.22	1.33
															0.5	17.57	7.03	2.21
GENERAL ELECTRIC CO.																		
8	MS0001N/P	S.C.	DF-2	23.5 (22.2)	11,984	< 10	147	187	8.4	23.5	7.8	6.0	0.27	0.75	0.1	30.6	1.30	3.86
															0.3	91.7	3.90	11.55
															0.5	153	6.50	19.25
9	MS7001B	S.C. & CCDF	N.B. DF-2	60.3 (49) & (59.4)	10,846	< 10	119	263	5.37	33.4	2.3	3.1	0.06	0.39	0	0	0	0
							163	371	5.78	46.7	0	0	0	0	0.1	71.1	1.18	8.46
															0.3	213	3.94	26.87
															0.5	355	5.89	44.8
10	MS7001B	R.C.	DF-2	57.4 (53)	8,876	< 10	373	930	16.2	117.8	5	7.6	0.16	0.97	0.1	55.4	0.96	6.98
															0.3	166	2.87	20.41
															0.5	277	4.82	34.9
11	MS7001C	S.C. & CCDF	DF-2	67.4 (66.2)	10,949	< 10	164	531	8.0	66.9	2.1	4.0	0.06	0.51	0.1	80.2	1.19	10.11
															0.3	241	3.67	30.32
															0.5	401	5.95	50.53
WESTINGHOUSE																		
12	1916	S.C.	DF-2	12.5	16,680	---	120	182	8.1	12.79	29	15.3	1.2	1.93	0.1	21.30	1.29	2.68
															0.3	63.91	5.11	8.05
															0.5	107	8.52	13.42
13	402510	S.C.	DF-2	29.2 (32.8)	13,420 (12,960)	---	189	340	11.9	49.2	31	39.4	1.2	4.97	0.1	42.59	1.46	5.37
															0.3	128	4.38	16.10
															0.5	213	7.29	26.83
14	4501B4	S.C.	DF-2	78.05	11,320	< 20	227	925	11.69	116.5	17.5	43.9	0.56	5.53	0.1	97.0	1.23	12.22
															0.3	291	3.69	36.67
															0.5	485	6.15	61.12
15	4501B	S.C.	DF-2	87.77	11,320	---	337	1578	17.97	199	---	---	---	---	0.1	108	1.23	13.61
															0.3	324	3.69	40.83
															0.5	540	6.15	68.0
TURNBULL																		
16	11C	S.C.	DF-2	51.7	11,889	8	315	318	15.67	102.1	30	47.2	0.9	5.95	0.1	66.6	1.29	8.40
															0.3	200	3.87	25.19
															0.5	332	6.45	41.93

Table 7-2 - NO_x Correlations for Gas Turbines

Source of Correlation	Equation	Definition of Terms
1. Combustion and Fuels Committee, American Society of Mechanical Engineers	$NO_x = [(NO_x)_{obs} \left(\frac{P_{3ref}}{P_{3obs}} \right)^{0.5} e^{19(H - .00633) \left(\frac{C(T_{3ref} - T_{3obs})}{T_{3ref} T_{3obs}} \right)}]$ $C_0 \left(\frac{f/a_{ref} - f/a_{obs}}{T_{3obs}} \right) e^{(T_{3obs})(f/a_{obs}) - T_{3ref}(f/a_{ref})}$ $\left(\frac{21-15}{21-0} \right) \left(\frac{21-0}{21-0} \right) \left(\frac{20.9-15}{20.9-0} \right) \left(\frac{f/a_{obs}}{2150} \right)$	<p>P₃ = Compressor discharge or regenerator discharge pressure H = specific humidity T₃ = compressor discharge or regenerator discharge temperature f/a = fuel/air ratio by weight C₀ = oxygen concentration by volume C, D, E = empirical constants obs = observed ISO = International Standard Organization, standard atmospheric conditions: 15°C (59°F), 1.013 bar (14.7 psia), 60% relative humidity (.00633 lb H₂O / lb air) ref = reference 2150 = determined from commonly used gas turbine performance calculations or curves.</p>
2. American National Standard Institute	$NO_x = (NO_x)_{obs} \left(\frac{P_{3ref}}{P_{3obs}} \right)^{0.5} e^{0.006(315 - T_{3obs})} \left(\frac{19(H_{obs} - .0064)}{[e^{(20.9-15)/(20.9-0)}] - 18640 \left(\frac{f/a_{obs}}{1 + (f/a_{obs})} \right) S H} \right)$	<p>P = burner inlet pressure in atmosphere T = burner inlet temperature in °C H = specific humidity ~ gm H₂O/gm air O₂ = exhaust oxygen, percent by volume f/a = fuel/air weight ratio N = fuel bound nitrogen ~ percent by weight obs = observed during tests Base conditions for equation P = 10 atmosphere (i.e. turbine has 10/1 compression ratio) T = 315°C (approximate heat of compression for 10 atm.) H = .00633 SO₂ = 15 S base as suggested by EPA in previous draft documents SH = NO₂ fuel has essentially no bound N</p>
3. General Electric - "A Constant Residence time equation for Correcting NO _x Emissions to a Set of Gas Turbine Operating Conditions--"	$NO_x = NO_{xref} \left(\frac{P_3}{P_{3ref}} \right)^{0.5} e^{(C_1 - 19.4H + C_2 \Delta T_3 + C_3 \Delta f/a)} \left(\frac{T_3}{T_{3ref}} \right)^{0.5}$	<p>NO_{xref} = NO_x measured at reference conditions of f/a, P₃, H, T₃. C₁ = (NO_{xref} machine X) - 1 ft. single machine model NO_{xref} machine Y P₃ = compressor or regenerator discharge pressure T₃ = Compressor or regenerator discharge temperature H = specific humidity ~ wt H₂O/wt dry air ref = reference condition f/a = fuel/air ratio by weight ΔH = H - H_{ref} ΔT₃ = T₃ - T_{3ref} Δf/a = f/a - f/a_{ref} C₁ = .00214 = empirical constant C₂ = 39,320 = empirical constant applies to constant speed simple cycle and regenerative machines and simple cycle variable speed machines.</p>
4. Pratt & Whitney - Turbo Power and Marine	$EI_{NO_x} = EI_{NO_{xobs}} \left(\frac{P_b ref}{P_b obs} \right)^{0.5} e^{0.00313[(T_b)ref - (T_b)obs]} \left(\frac{19(H - .00634)}{e^{(20.9-15)/(20.9-0)} - 18640 \left(\frac{f/a_{obs}}{1 + (f/a_{obs})} \right) S H} \right)$	<p>EI = emission index ~ g NO_x emitted / kg fuel P_b = burner pressure T_b = temperature at burner inlet H = specific humidity obs = observed conditions ref = reference conditions</p>
5. Westinghouse	$\frac{NO_x}{(NO_x)_{ref}} = \left(\frac{P}{P_{ref}} \right)^{0.5} e^{\left[\frac{(T - T_{ref})}{255} + \frac{(\Delta T - \Delta T_{ref})}{641} + 12(H_{ref} - H) \right]}$	<p>P = compressor discharge pressure - Psia T = Compressor discharge temperature - °F ΔT = combustor temperature rise - °F H = specific humidity ref = values of parameters at the reference condition NO_x = ppm(v) - expressed as NO₂ ΔT₀₄ f/a</p>
6. Detroit Diesel Allison Division of General Motors	The humidity correction factor used is 19(H-.00633). Other corrections were obtained by computer analysis of test data to provide equations for correlating emissions from the 501 E engine.	
7. Solar	The equation which GE proposed for correcting NO _x emissions (see item 3 of this table) is not applicable to Solar engines. Solar believes the constants in that equation will differ "depending on whether the engine is single shaft, two shaft, simple cycle, or regenerative cycle as well as combustor type."	
8. Garrett Airresearch	Emission data not sufficient to indicate a preferable correlation. Use humidity correction: NO _x corrected = (NO _x measured) e ^(19H - .00634) Temperature correction: Lipfert curve (from literature) fits their engines fairly well.	
9. Turbodiesel	Humidity: NO _x = (NO _x measured) e ^{15.73 (H - .00634)} Temperature: "It appears that for each gas turbine there exists a unique relationship between ambient temperatures and NO _x emissions." They suggest that each manufacturer be permitted to establish the NO _x - temperature curve for each specific engine - combustor combination.	

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Table 7-3 - Fuel Properties, Natural and Synthetic Fuels
Used in the EPA "Rich Burn-Quick Quench" Program

	No. 2 (Typical)	SRC II Middle Distillate	Indonesian/ Malaysian Resid	Shale Resid
Specific Gravity	0.84 (60°F)	0.87 (60°F)	0.87 (210°F)	0.82 (210°F)
Viscosity, centistokes	5.0 (60°F)	6.3 (60°F)	11.6 (210°F)	3.3 (210°F)
Surface Tension dynes/cm	25.7 (60°F)	33.3 (60°F)	22.6 ^a (210°F)	20.6 ^a (210°F)
Heat of Combustion (net) Btu/lbm	18,700	17,235	17,960	18,190
Pour Point °F	<5	<-45	61	90 (remains waxy)
Flash Point °F	>130	>160	210	235
Ultimate Analysis				
Carbon %	87.0	85.77	86.53	86.71
Hydrogen %	12.8	9.20	11.93	12.76
Nitrogen %	<0.02	0.95	0.24	0.46
Sulfur %	0.04-0.48	0.19	0.22	0.03
Ash %	<0.003	0.001	0.006	0.009
Oxygen %	<0.09	3.89	—	0.03
Conradson Carbon, Residue %	<0.30	0.03	3.98	0.19
End Point °F, Atmos. Distillation	640	541	NA	700
NOTES:				
^a Fuel properties are given at stand delivery temperatures to be maintained in test program.				
^b Estimate on basis of fuel specific gravity.				

Table 7-4 - CO and HC Emissions at Various
Combustion Efficiencies

Turbine load horsepower	0	121	168	192
Combustion Efficiency %	97.2	98.6	99.3	99.6
Hydrocarbons as HC ₄ lbs/hr	1.576	0.627	0.141	0.061
HC ppm @ 15% O ₂	495	134	26	10
Carbon Monoxide lbs/hr	7.37	7.21	5.38	3.34
CO ppm @ 15% O ₂	1324	880	566	315

Table 7-5 - Water Quality Specifications

	<u>Turbine</u>	<u>Boiler Feed</u>
Total Dissolved Solids (TDS) + Non Dissolved Solids (ppm)	1.0 - 5.0	0.25
Sodium + Potassium (ppm)	0.5 ^a	0.25
Silica (ppm)	0.02	0.0
Particle Size (micron)	10	--
pH	7.0 - 8.5	6.5 - 7.0
^a Turbo Power & Marine limits sodium to 0.1 ppm.		

Table 7-6 - NO_x Emissions Reported Using the
"Rich Burn/Quick Quench Combustor

Fuels Tested	% Nitrogen Content	NO _x Emissions (ppm)
#2 Distillate	-	40-45
#6 Indonesian Resid	0.24	75
#6 Shale Oil Resid	0.46	65
Middle Distillate SRC-II Oil	0.95	90

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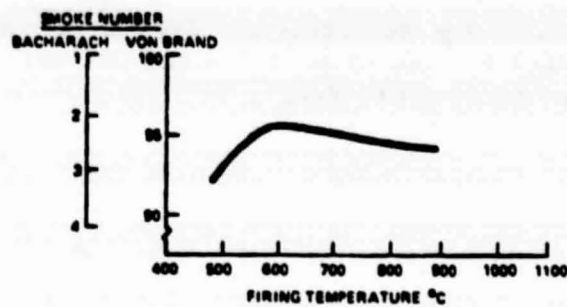


Figure 7-1 - Visible Emissions vs. Firing Temperature
(Load) for a GE MS-5001 Turbine Burning
Residual Fuel

Note: Visible emissions decrease with increasing
von Brand number and decreasing Bacharach
number.

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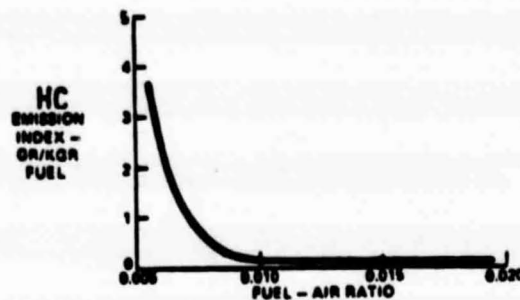


Figure 7-2 - Hydrocarbon Emissions vs. Fuel-to-Air Ratio (Load) for the GE MS-7001B and MS-5001N Turbines When Burning Oil Fuel

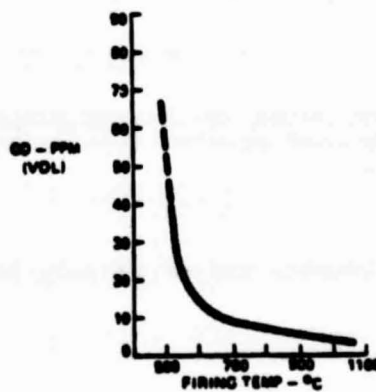


Figure 7-3 - Carbon Monoxide Emissions vs. Firing Temperatures (Load) for GE Gas Turbines Burning Oil Fuel

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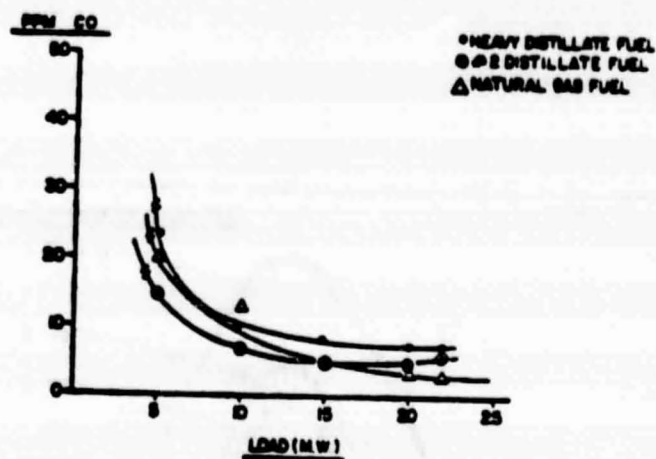


Figure 7-4 - CO Emissions vs. Turbine Load for Various Fuels

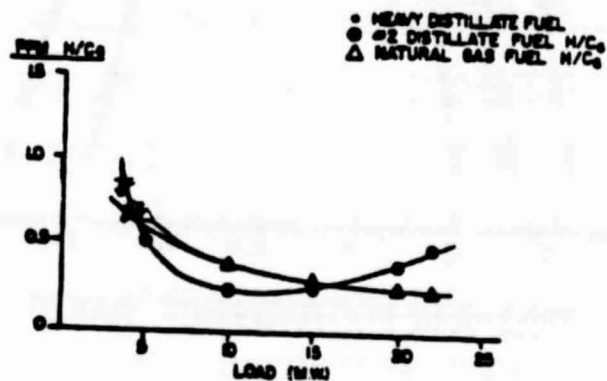


Figure 7-5 - HC Emissions vs. Turbine Load for Various Fuels

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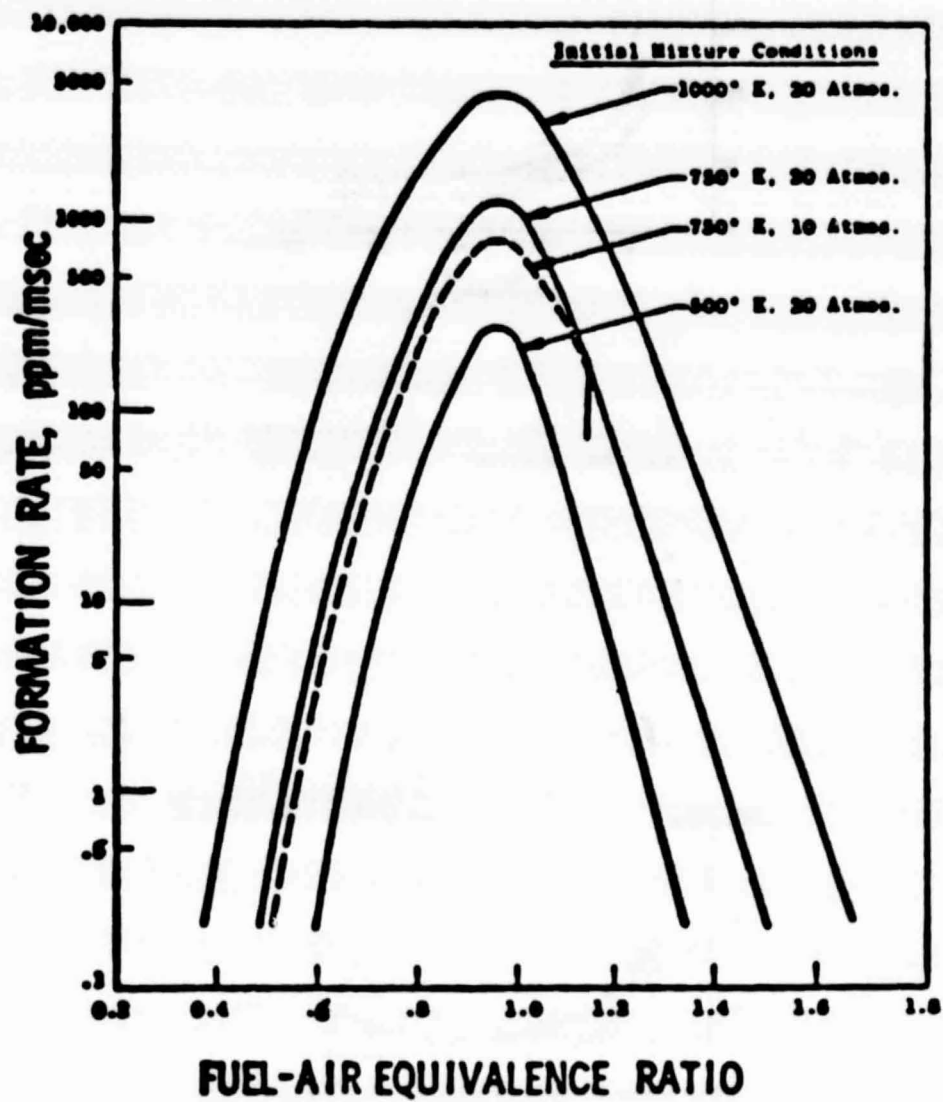


Figure 7-6 - Formation Rate Data for NO_x

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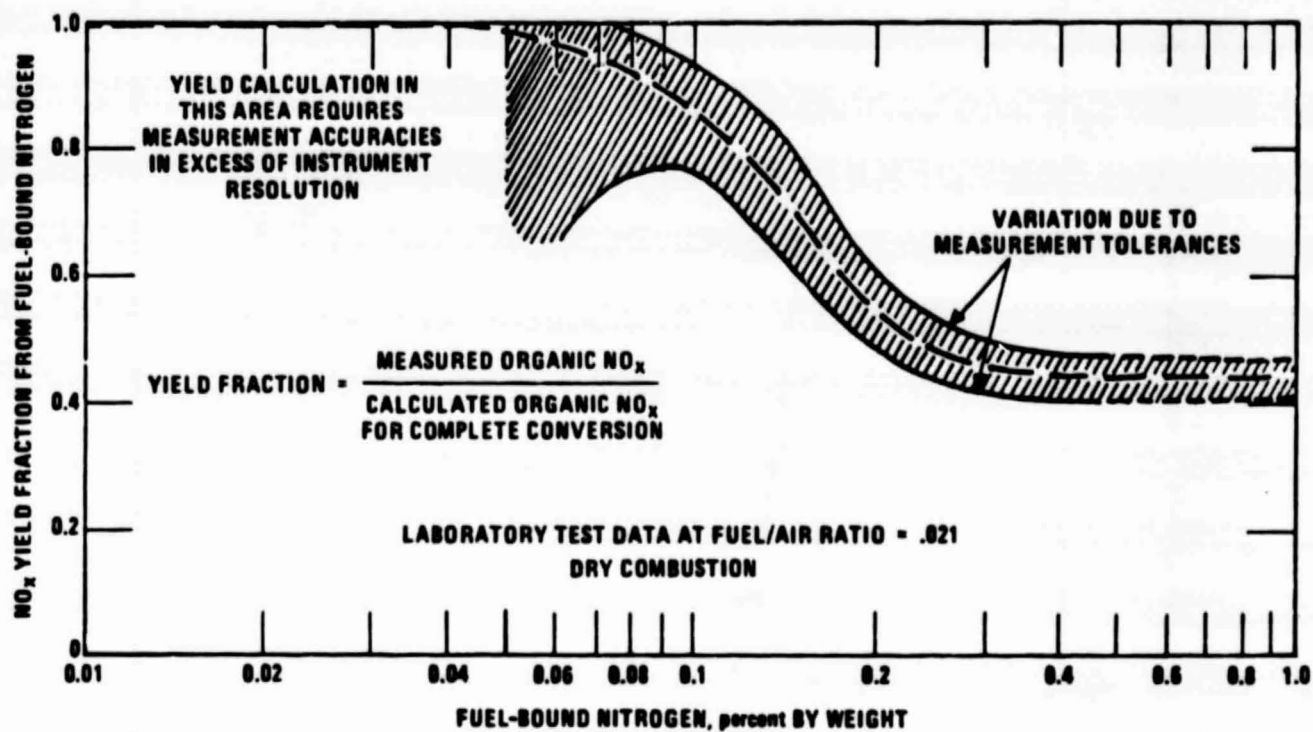


Figure 7-7 - NO_x Yield Fraction vs. Fuel-Bound Nitrogen Content

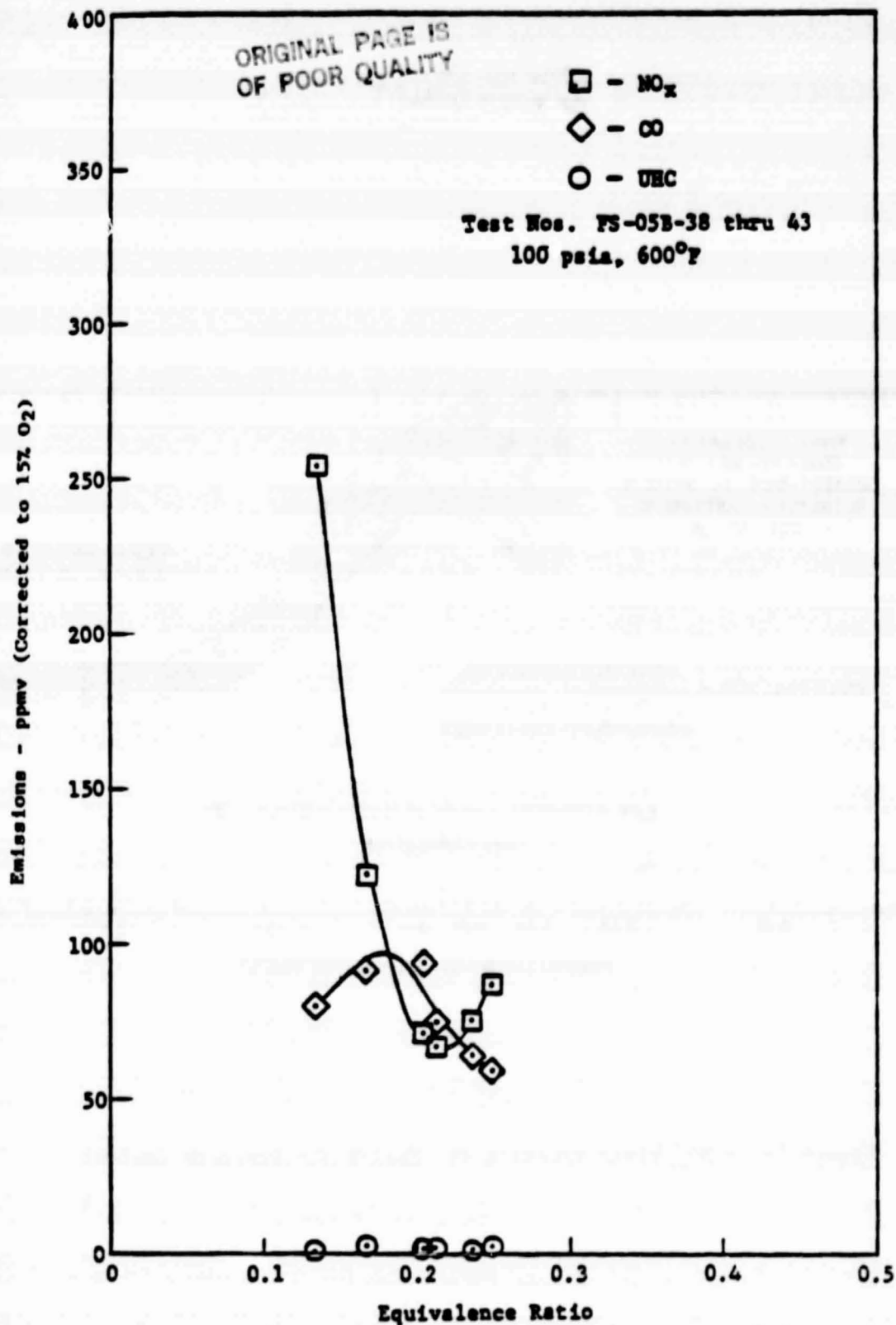


Figure 7-8 - Emission Signature of Scheme FS-05B Firing
Indonesian/Malaysian Residual

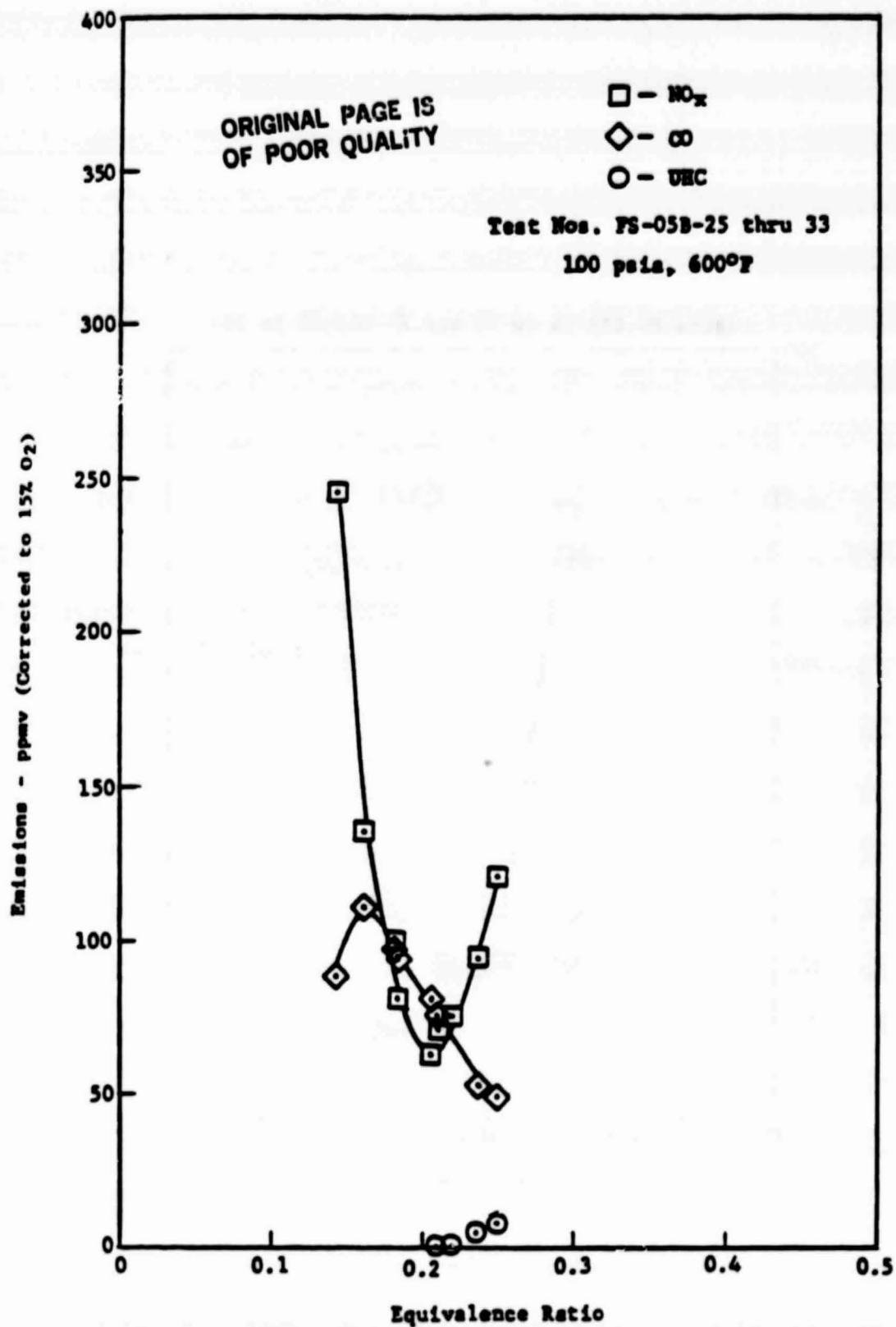


Figure 7-9 - Emission Signature of Scheme FS-05B Firing Shale Residual

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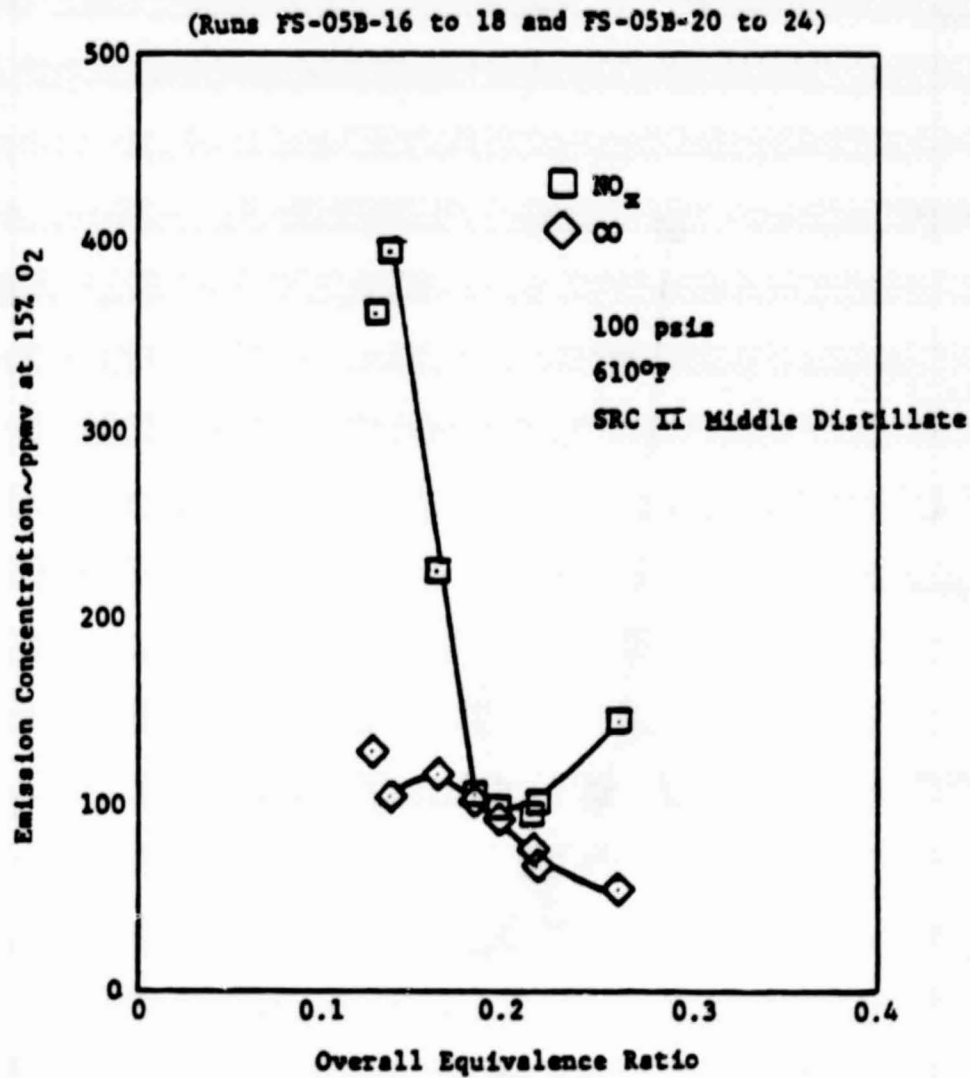


Figure 7-10 - Variation in Emission Concentrations With Overall Equivalence Ratio for Scheme FS-05B Using SRC II Middle Distillate Fuel

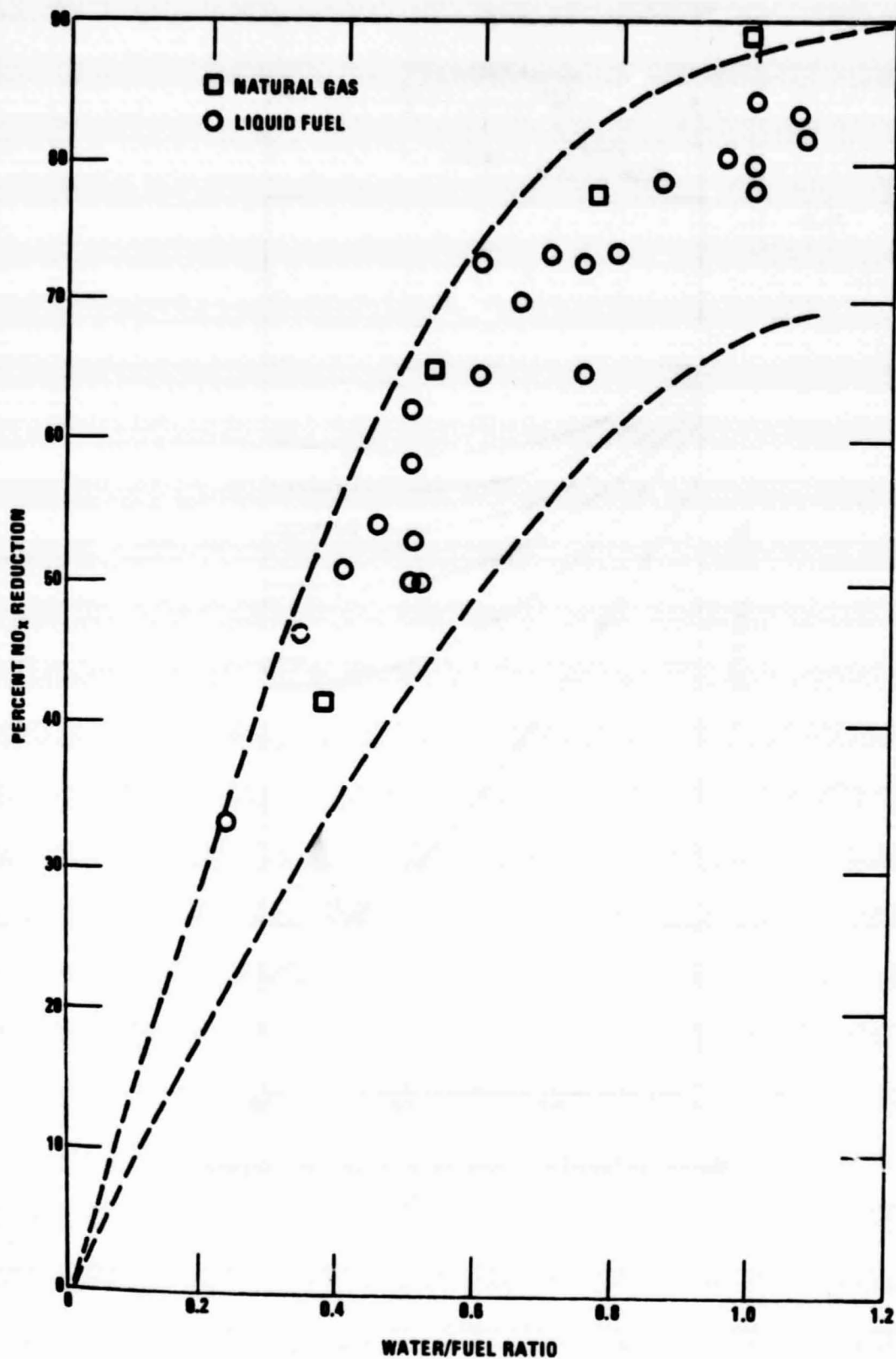


Figure 7-11 - Effectiveness of Water/Steam Injection in Reducing NO_x Emissions

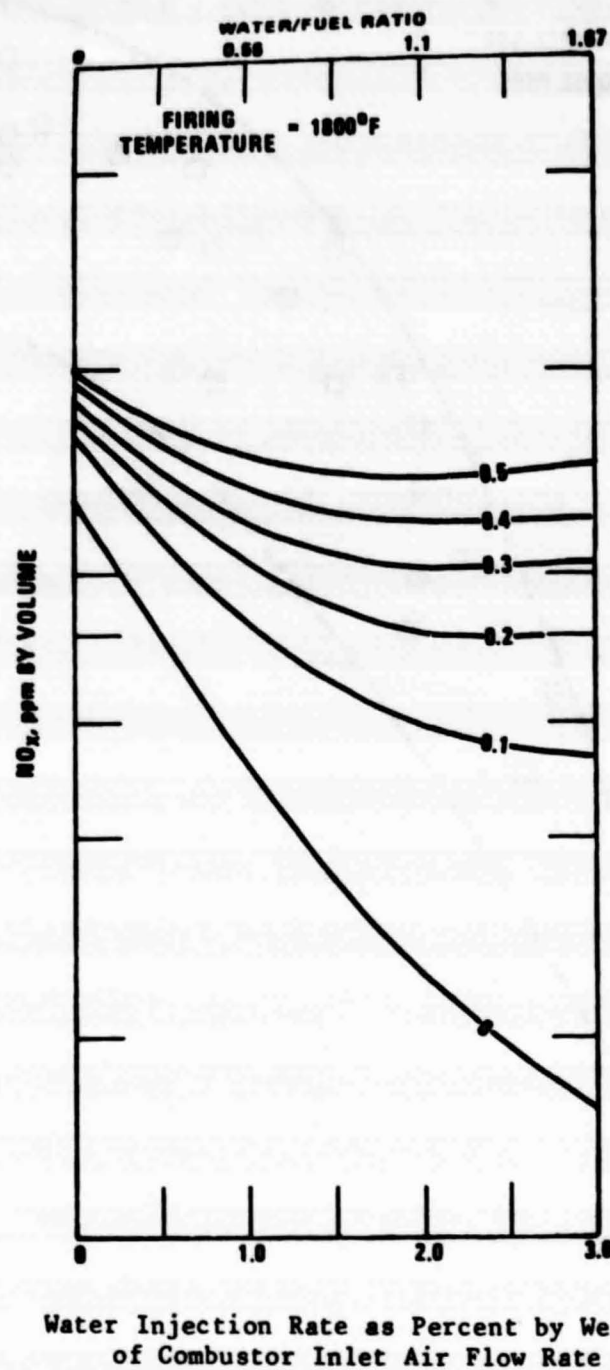


Figure 7-12 - Predicted NO_x Emissions for a Range of Nitrogen Contents and
Water Injection Rates

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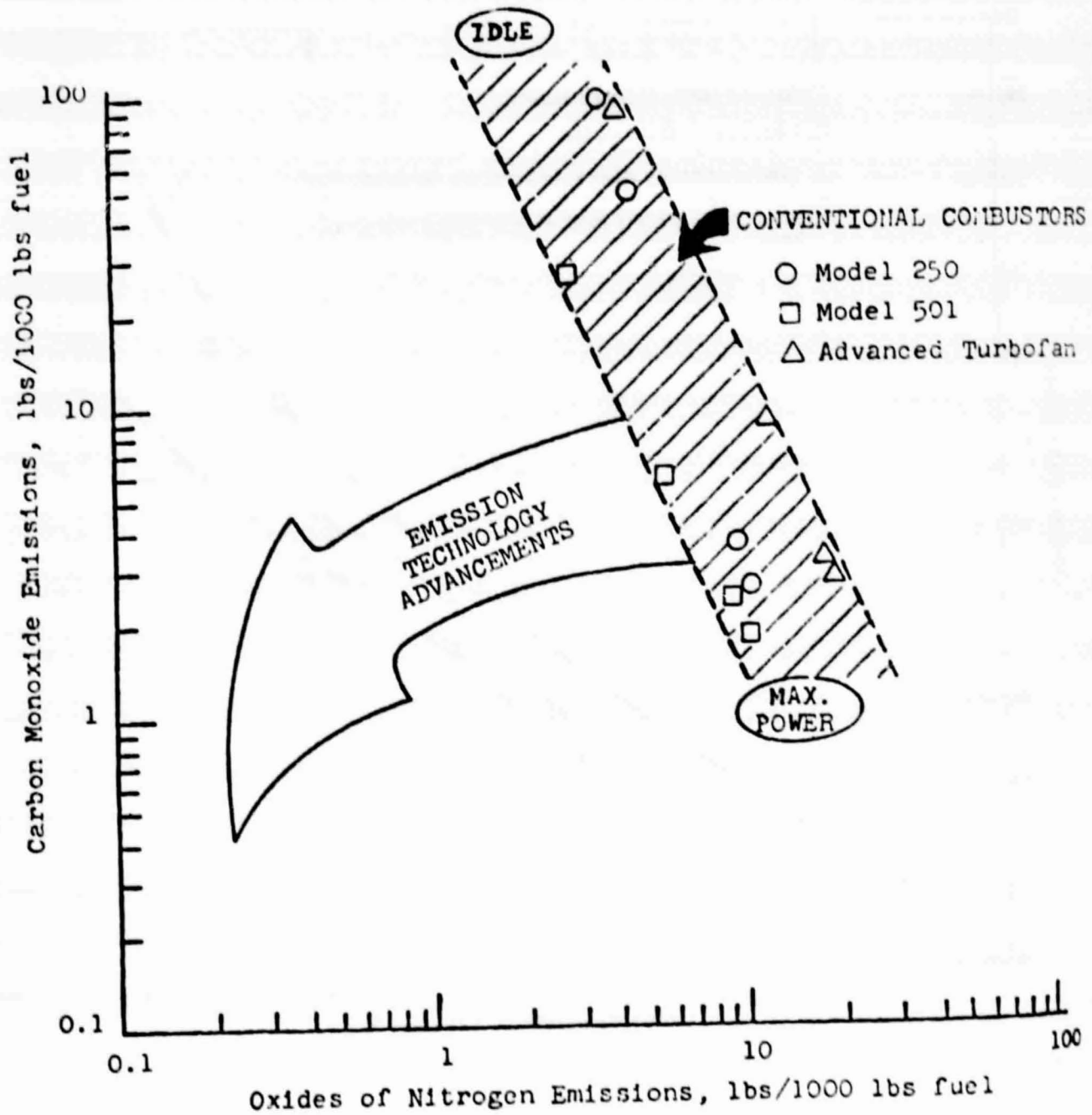


Figure 7-13 - CO and NO_x Performance of Conventional
Gas Turbine Combustors

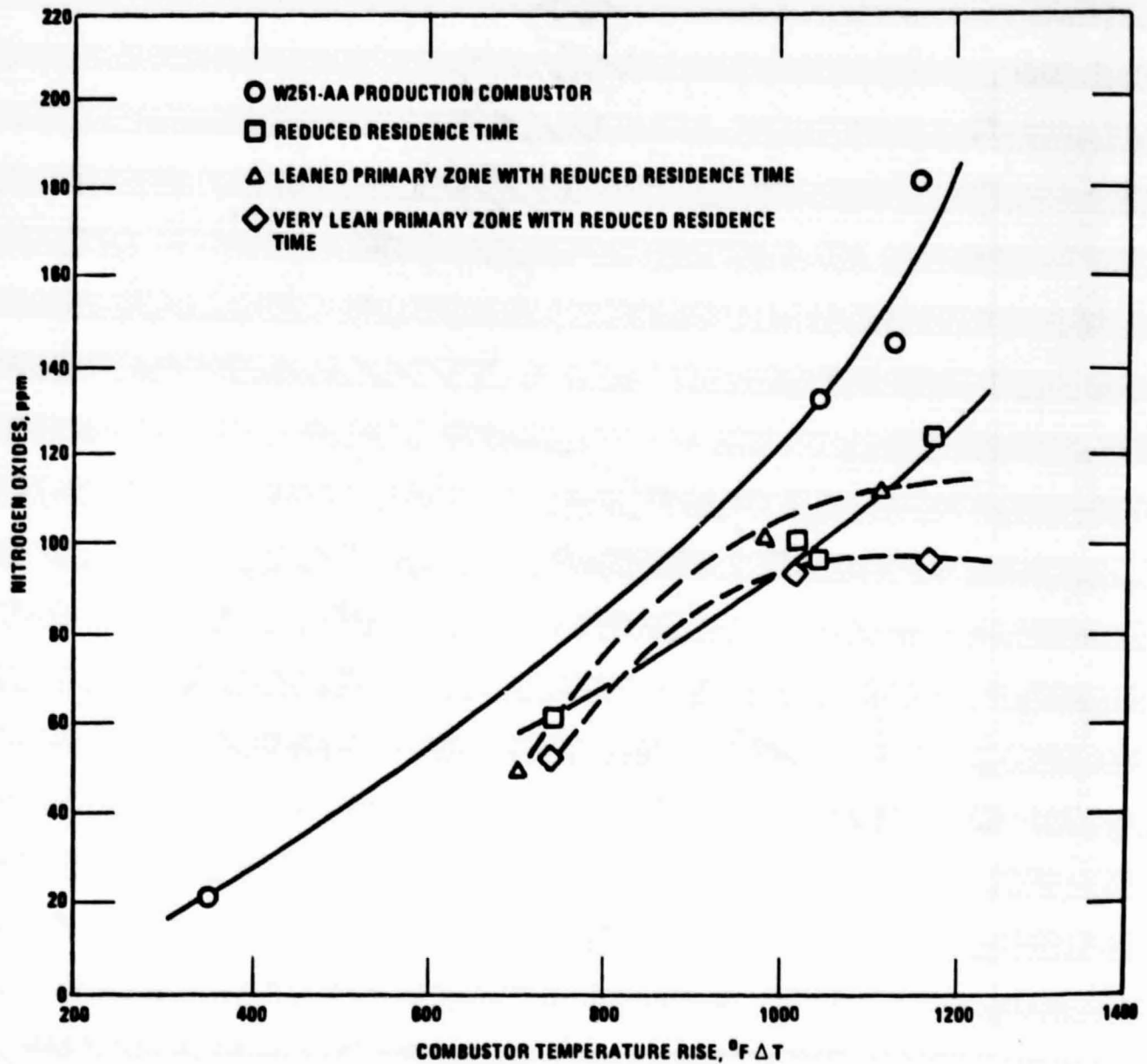


Figure 7-14 - NO_x Emissions Versus Combustor Temperature Rise for a Production Combustor and Several Modified Versions of the Production Combustor

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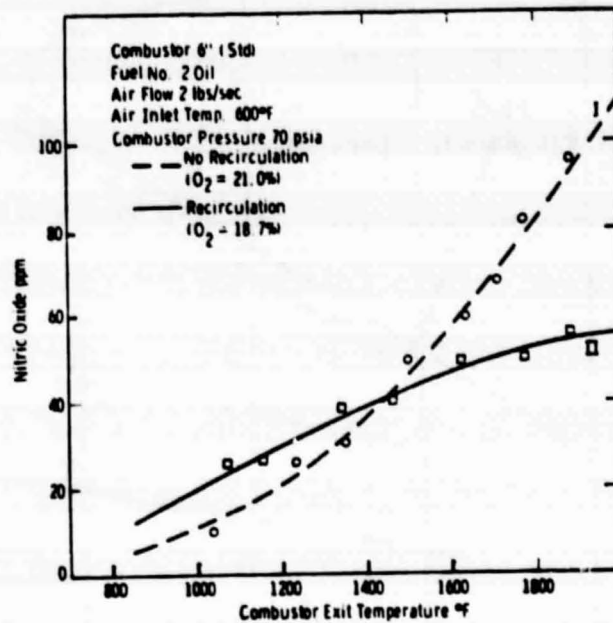


Figure 7-15 - Effect of Exhaust Gas Recirculation on NO Emissions
for a Combustor Burning No. 2 Oil

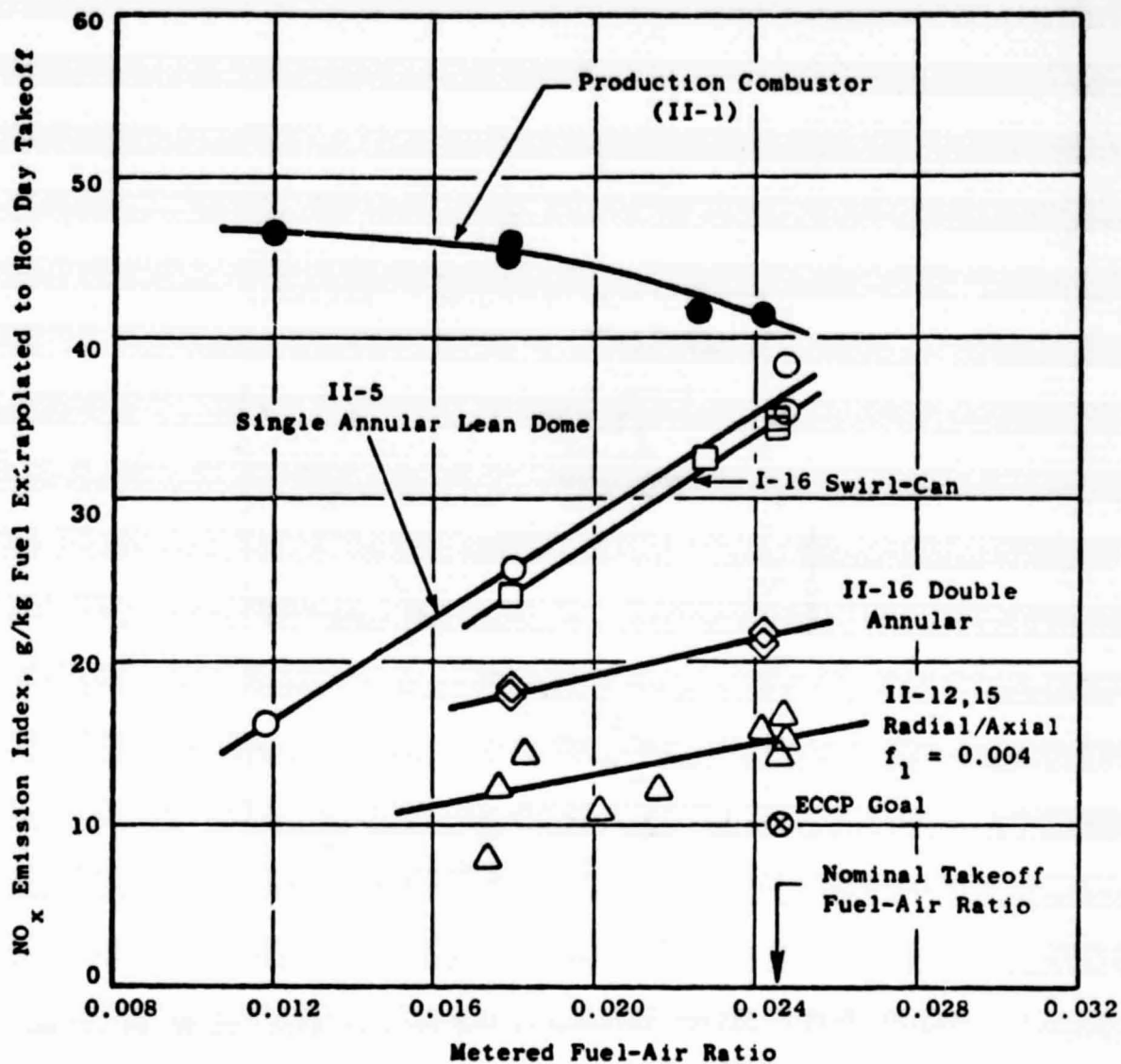


Figure 7-16 - NO_x Emissions Levels, Best Configuration of Each Major Design Approach

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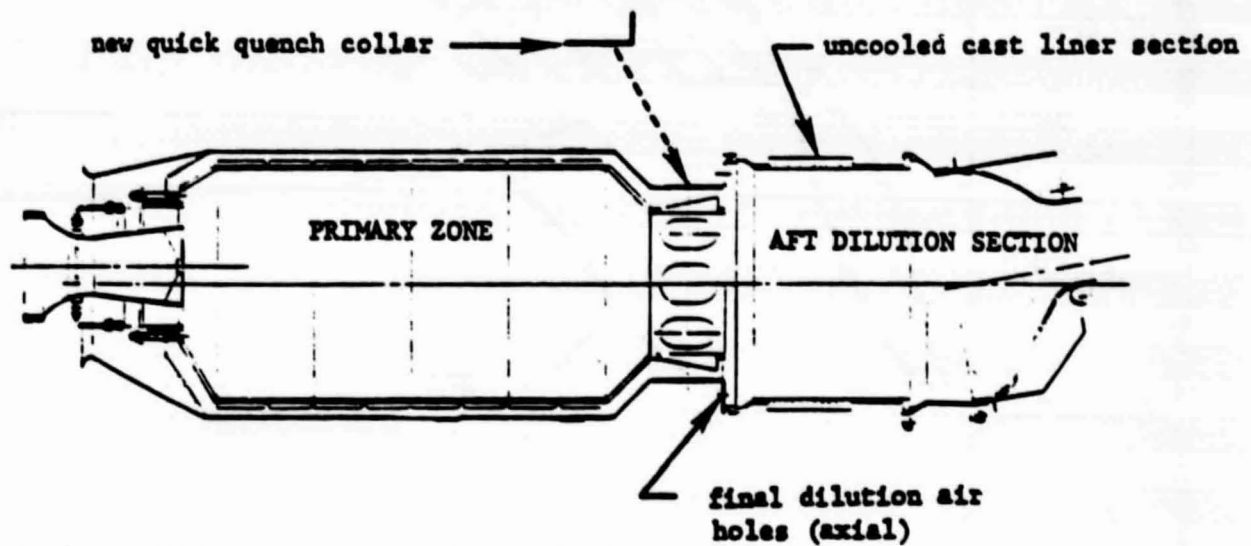


Figure 7-17 - Rich Burn/Quick Combustor Configuration

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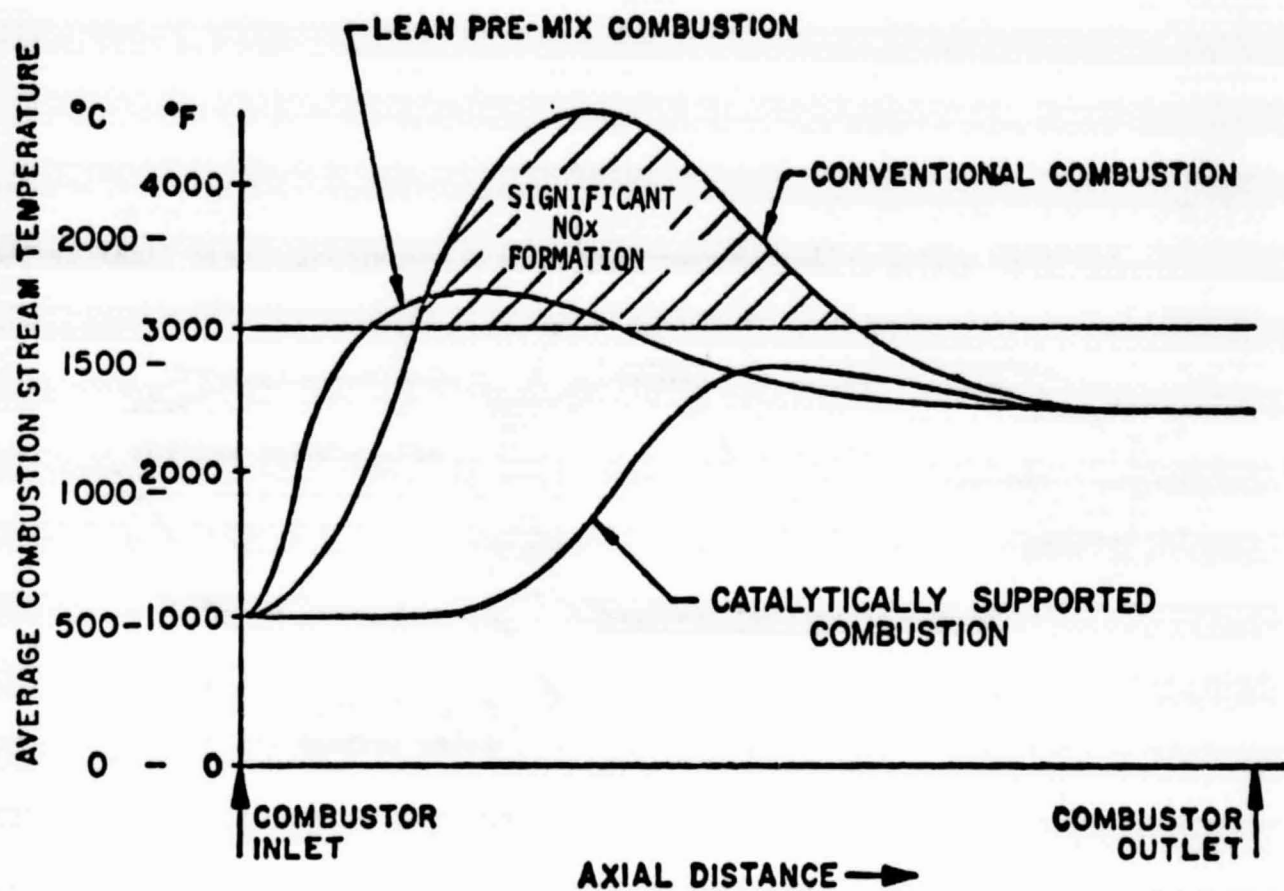
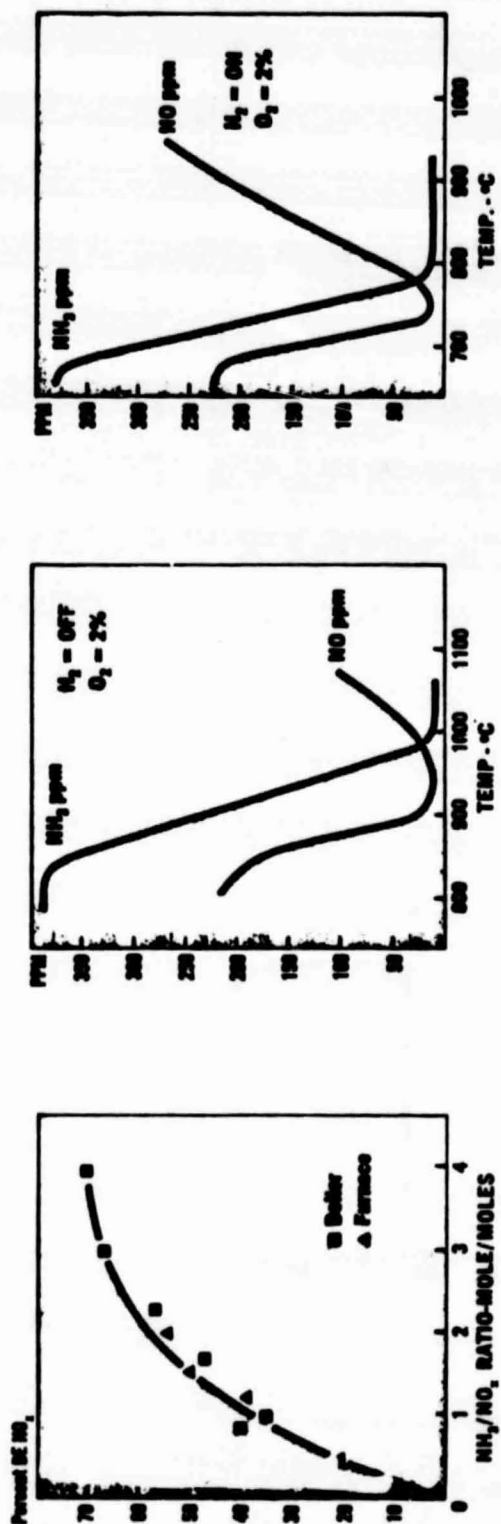


Figure 7-18 - Temperature History for Conventional Combustors, Lean Pre-Mix Combustors, and Catalytically Supported Combustion



Figures 7-19, 20, 21 - Behavior of Exxon Thermal De NO_x Process

Source: Exxon Research & Engineering

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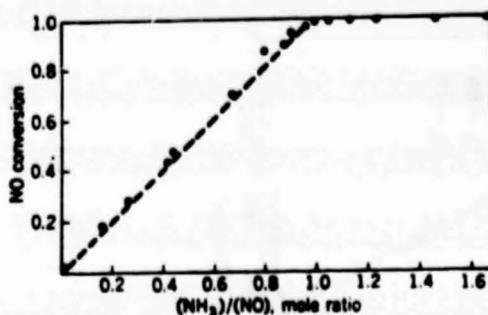


Figure 7-22 - NO Conversion as a Function of (NH₃)/(NO) Ratio. Gas Mixture: 300 ppm NO, 0-500 ppm NH₃, 3% O₂ and the remainder N₂. Reaction Temperature: 350°C, Space Velocity 300,000 h⁻¹, Catalyst: NR-500.

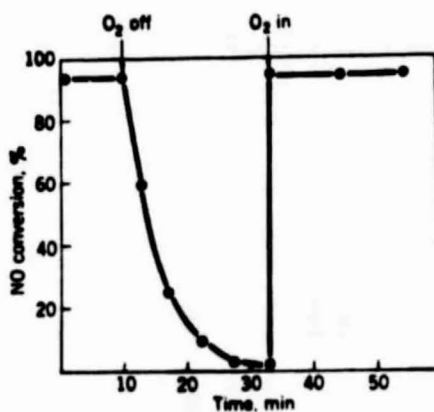


Figure 7-23 - Effect of Oxygen on NO-NH₃ Reaction. Gas Mixture: 300 ppm NO, 360 ppm NH₃, 0 or 3% O₂, and the remainder N₂. Reaction Temperature: 350°C, Space Velocity: 50,000 h⁻¹, Catalyst NR-500.

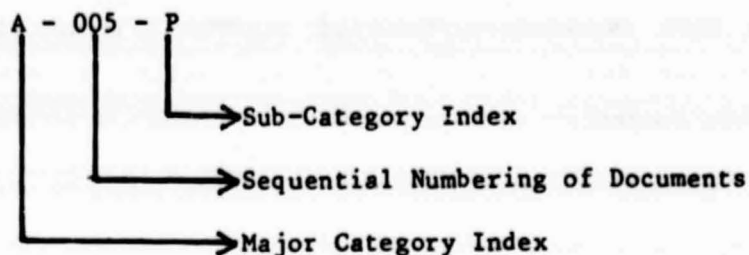
APPENDIX A

LITERATURE SEARCH DOCUMENT LIST AND ABSTRACTS

This list represents preferred reports selected from the literature search and procured for active reference use on this project.

NASA-Lewis Fuel Processing/Study
Task I Literature Search Documents

Legend: Example Document No.



Major Categories

- A Coal Derived Synfuels
- B Oil Shale - Tar Sand Synfuels
- C Petroleum (Reference Distillate and Residual) Fuels
- D Turbine Fuel Standards and Specifications
- E Turbine Fuel Pretreatment
- F Turbine Technology and Emission Controls

Sub-Categories

- M Economics Items (product market costs, fixed capital investment and other economic factors)
- N Environmental
- P Physical and Chemical Properties
- T Production Technology
- Y Energy Efficiencies

A-001-P, B-001-P

REFINING OF SYNTHETIC CRUDES, Advances in Chemistry Series 179, American Chemical Society, Washington, D.C., 1979

Abstract: Based on a symposium sponsored by the Division of Petroleum Chemistry at the 174th Meeting of the American Chemical Society, Chicago, Illinois, August 29 - September 1, 1977. Papers presented discuss Characterization of Syncrudes, Analysis of Hetero compounds in coal liquids, hydroprocessing of shale oil, two-staged thermal and catalytic hydrocracking process for athabasca bitumen, catalytic cracking of ridge bitumen, upgrading of primary liquids by hydrotreatment, catalytic hydroprocessing of solvent refined coal, investigation of cobalt-molybdenum - alumina catalysts for hydronitrogenation of coal derived oils, catalytic effect of active metals upon hydrodenitrogenation of heavy coal liquids, chemicals from coal-derived synthetic crude oils.

A-002, B-002

Schweiger, Robert G., "BURNING TOMORROW'S FUELS", Power, February, 1979.

Abstract: Discussion of combustion characteristics of various synthetic fuels utilized in industrial boilers, gas turbines and process equipment. Includes low, medium and high BTU SNG, coal derived liquids, oil shale liquids and solvent refined coal.

A-003-P, B-003-P, D-004-P, F-008-P

Moses, C. A., Naegeli, D. W., "FUEL PROPERTY EFFECTS ON COMBUSTOR PERFORMANCE", Southwest Research Institute, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San-Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-178.

Abstract:

Two combustor rigs have been used to study the sensitivities of combustor operation to the physical and chemical properties of fuels. Nineteen fuels including synfuels were used to accentuate the properties of concern: composition, viscosity and boiling-point distribution. Flame radiation and smoke were best correlated by hydrogen content rather than hydrocarbon structure; the soot formation was due to gas-phase reactions. Lean-blowout conditions were about the same for all fuels except that gasoline could be burned leaner at idle conditions. Ignition limits were more sensitive to volatility than viscosity. Gaseous emissions and combustion efficiency were not significantly affected by fuel properties although some sensitivity to boiling point distribution was evident. In all performance areas the syncrude fuels correlated in the same ways as the petroleum-derived fuels except for the NO_x emissions from the nitrogen containing shale oil fuel.

A-004-P, B-004-P

Synthetic Fuel/Turbine Fuel

Gallagher, J.P., ARCO, Harvey, Illinois "SYNTHESIS AND ANALYSIS OF JET FUEL FROM SHALE OIL AND COAL SYNCRudes" prepared for NASA/Lewis Research Center, Contract No. NAS 3-19747, November 1976.

Abstract: Thirty-two jet fuel samples of varying properties were produced from shale oil and coal syncrudes, and analyzed to assess their suitability for use. TOSCO II shale oil, H-Coal and COED syncrudes were used as starting materials.

A-005-P

Synthetic Fuels

Lanning, W. C., Bartlesville Energy Research Center, Bartlesville, Oklahoma, "THE REFINING OF SYNTHETIC CRUDE OILS" Report prepared for the ERDA, Technical Information Center, July 1976.

Abstract: Investigation of synthetic crude oils on the basis of experimentally determined composition of these oils and other published information. Characteristics of the synthetic crude oils which indicate the crucial requirements for refining are reviewed. General introduction.

A-006

Coal Conversion

Editors of "Chemical Engineering Program "COAL PROCESSING TECHNOLOGY" published by AIChE, 1977, from Oak Ridge National Laboratory (Holmes, Cochran, Edwards, Joy, Lantz)

Abstract: Evaluation of seven coal carbonization processes, COALCON, CSIRO CLEAN COKE, COED, GARRETT, LURGI, CONSOL. Yield comparison of these processes and oil/gas production in relation to temperature and pressure.

A-007

Coal Conversion

Edward, J. H., CSIRO Division of Process Technology, North Ryde, N.S.W. "OIL-FROM-COAL PROCESSES: A CRITICAL EVALUATION FOR AUSTRALIAN CONDITIONS" Sixth national Chemical Engineering Conference, Queensland, Australia. November 6-8, 1978.

Abstract: The results of a critical evaluation of nine coal liquefaction processes are presented and discussed with a list of "First Generation" and some "Second Generation" processes.

A-008-P

Coal Liquefaction

The Ralph M. Parsons Company "COAL LIQUEFACTION PROCESS RESEARCH PROCESS SURVEY" (HC Process Department) prepared with Union Carbide Corporation, Nuclear Division for DOE, principal Contract No. W-7405-eng.-26, December 1977.

Abstract: Data Source Book of the coal liquefaction processes, selected from those surveyed and judged to have a high commercial potential. Contents: Process Description, Process Development, Operating Conditions and Products of 32 coal liquefaction processes.

A-009-P

Coal Liquefaction/Reaction Investigation

Gary, Golden, Bain, Dickerhoof, Chemical and Petroleum-Refining Engineering. Department Colorado School of Mines, Golden, Colorado. "CLEAN SOLID AND LIQUID FUELS FROM COALS" Quarterly Progress Report, July - September 1978, prepared for DOE, contract No. EX-76-C-01-2047, 125 pages.

Abstract: Preliminary analysis of yield structure as a function of temperature and reactor residence time. An ancillary study to investigate the effects of mineral matter, gaseous hydrogen and residence time upon the conversion of a HVA bituminous coal is presented also.

A-010

Coal Oil/Crude Oil

Conses, R. E., Garrett, G. M., Weismann, J. A., UOP Process Division, Des Plaines, Illinois "CRUDE OIL VS. COAL OIL PROCESSING COMPARISON STUDY" presented at AIChE, Boston, Massachusetts, August 1979.

Abstract: This study evaluates three refinery schemes for the processing of H-Coal liquid obtained from the HRI coal liquefaction process:

1. Hydrotreating of the middle coal distillate.
2. Hydrocracking of the total coal distillate.
3. Hydrotreating of the light coal distillate, and hydrotreating of the heavy coal distillate.

To provide a perspective of the value of coal liquid relative to petroleum, a parallel set of petroleum refinery schemes was developed.

A-011-P

Coal Liquefaction/Properties

De Rosset, Tan, Gatsis, Shoffner, Swensen; UOP Research Center, Des Plaines Illinois "CHARACTERIZATION OF COAL LIQUIDS" Prepared for the ERDA, contract No. E(49-18) 2010, March 1977, 134 pages.

Abstract: Investigation to evaluate the processability of the primary products of coal liquefaction generated by three processes: Synthoil, SRC, H-Coal. Analytical characterization of charge and production streams. The results indicate possible upgrading of coal liquids using technology now available.

A-012

Coal Conversion/Pyrolysis

From Technical Data Book, IGT "CONVERSION FUNDAMENTALS" March 1977

Abstract: Effect of Pressure on Pyrolysis.

A-013-P

Coal Conversion/Catalytic Hydrocracking

Qader, S. A., Occidental Research Corporation, La Verne, California "CATALYTIC HYDROCRACKING OF COAL FOR CHEMICALS AND CLEAN FUELS" Papers for Presentation at the 82nd AIChE National Meeting, Atlantic City, N. J. August/September 1976.

Abstract: Process description and product analysis.

A-014

Coal Liquefaction/Hydrogenation

Falk, A. Y., Enery System Group, Rockwell International "PARTIAL LIQUEFACTION OF COAL BY DIRECT HYDROGENATION" Quarterly Progress Report October-December 1978, prepared for DOE, under contract EX-76-C-01-2044, 10 pages.

Abstract: Short introduction in the working program and brief process description. Final report should be finished by December, 1979.

A-015

Coal Conversion/Upgrading

DeRosset, A. J., Tan, G., Hilfman, L. UOP Inc., Des Plaines, Iowa. "UPGRADE COAL DERIVED DISTILLATES" from Hydrocarbon Processing, API Refining Meeting, May 1979, 3 pages.

Abstract: Hydrotreating, hydrocracking, reforming and fluid catalytic cracking are tried on distillates from three coal liquefaction process to explore possibilities for alternate fuels.

A-016

Coal Conversion/Fuel Specifications

State Electricity Commission of Queensland, Australia "RE: COAL CONVERSION STUDY". Letter from E. M. Robinson (Australia) to J. B. O'Hara (RMP) on June 7, 1979.

Abstract: Specification sheets for:

- Aviation turbine fuels
- Premium gasoline
- Regular gasoline
- Automotive diesel oil
- Industrial diesel oil.

A-017

Coal Liquefaction/Fuel Treatment

- a) Peluso, M., D. F. Ogren, C-E Lummus, Bloomfield, New Jersey "ANTISOLVENT DEASHING"
- b) Adams, Knebel, Rhodes; Kerr-McGee Corporation, Oklahoma City "CRITICAL SOLVENT DEASHING OF LIQUEFIED COAL" In Chemical Engineering Progress, pages 41-48, June 1979.

Abstract:

- a) Advanced solid-liquid separation technique over current filtration.
- b) Deashing of a wide range of feedstock to less than 0.1 wt.%.

A-018

Coal Liquefaction/Fuel Treatment

Gallagher, Humes, Siemssen, Atlantic Richfield Company, Harvey, Illinois. "CAT-CRACKING TO UPGRADE SYNTHETIC CRUDES" in Chemical Engineering Progress, p. 56-62, June 79.

Abstract: Fluid catalytic cracking of synthetic crudes from oil shale and coal (comparison of different yields). Influence on Nitrogen level.

A-019

Coal Liquefaction/SRC and H-Coal

The Ralph M. Parsons Company. "PROCESS ENGINEERING EVALUATIONS OF ALTERNATIVE COAL LIQUEFACTION CONCEPTS" (G. A. White, G. P. McNamee, N. K. Patel, I. R. Roszkowski) prepared for EPRI AF-741, Final Report, April 1978.

Abstract: Process engineering evaluation of two coal liquefaction concepts: Solvent refined coal and a generic catalytic hydroliquefaction process. Engineering design and cost estimates for a southern Illinois location. Size of plant 50,000 FOE bbls/day. On site and off site power generation possibilities. Tables of product yield structure, basic information of products.

A-020

Coal Liquefaction/SRC Hydrogenation Catalyst

Berg, L., McCandless, F. P., Montana State University, Bozeman, Montana. "CATALYTIC HYDROGENATION OF COAL-DERIVED LIQUIDS" Interim Report for the period March - May 1979, prepared for DOE, contract No. E(49-18)-2034, June 1979

Abstract: Begin of test runs using catalysts for denitrogenation and desulfurization at 730°F and 1050 psig.

A-021

Coal Liquefaction/Hydrotreating Catalyst SRC

Potts, J. D., Hartings, K. E., Cities Service Company, Technology Assessment Department, Tulsa, Oklahoma. "COMMERCIAL SCALE EXPANDED BED HYDROPROCESSING OF SRC EXTRACT" Interim Technical Progress Report on Subtask I - Catalyst Screening, prepared for DOE, Contract No. EX-76-C-01-2038, August 1978, 63 pages.

Abstract: The objective of this subtask is to determine the effectiveness of commercially available hydrotreating catalysts for improved denitrogenation. Set goal is 0.3 wt.% - 780-850°F fraction.

A-022

Coal Liquefaction/SRC and Related Processes

Guin, J. A., Tarrer, A. T., Coal Conversion Laboratory, Auburn University Department of Chemical Engineering Auburn Alabama. "STUDIES IN COAL LIQUEFACTION WITH APPLICATION TO THE SRC AND RELATED PROCESSES". Quarterly Report October - December 1977, prepared for DOE, Contract No. EX-76-S-01-2454, 117 pages.

Abstract: Investigation of fundamental aspects of the coal conversion process, especially SRC. Influence of particle size and catalyst (minerals) on reaction. Research program.

A-023

Coal Liquefaction/SRC

The Pittsburgh & Midway Coal Mining Company, Shawnee Mission, Kansas "SOLVENT REFINED COAL (SRC) PROCESS" Quarterly Technical Progress Report, July - September 1978, prepared for DOE, Contract No. EX-76-C-01-0496, 87 pages.

Abstract: Summary of the progress of the SRC project by the Pittsburgh & Midway Company. Testing of a new type rotary drum filter, novel reactor and very short residence time and a study of solvent behavior at SRC II reaction conditions at the Fort Lewis Pilot Plant. At the process development unit P-99 a series of Pittsburgh seam coals was tested to study the influence on feedstock effects and process variable effects.

A-024

Coal Liquefaction/H-Coal H-Treating

Tan G., DeRosset, A. J., UOP Inc. Des Plaines, Illinois "HYDROTREATING AND REFORMING H-COAL PROCESS DERIVED NAPHTHAS" Interim Report from "UPGRADING OF COAL LIQUIDS" prepared for DOE, Contract No. EF-77-C-01-2566, April 1978.

Abstract: Evaluation of the applicability of commercial UOP hydrotreating and reforming processes to naphthas derived from the H-Coal process. Three naphthas were studied. The upgraded H-Coal naphtha and the two hydrocracked naphthas were reformed over a commercial platforming catalyst in bench scale continuous units. Datas were obtained at base pressure, 1.5 x base space velocity, and a range of temperatures for the purpose of constructing yield octane curves.

A-025

Coal Liquefaction/H-Coal Catalytic Cracking

Tan G., DeRosset UOP Inc., Des Plaines, Illinois "HYDROTREATING AND FLUID CATALYTIC CRACKING OF H-COAL PROCESS DERIVED GAS OILS". Interim Report from "Upgrading of Coal Liquids" prepared for DOE, Contract No. EF-77-C-01-2566, August 1978.

Abstract: Evaluating the applicability of commercial UOP hydrotreating and fluid catalytic cracking (FCC) processes to distillate liquids derived from H-Coal processes. Three UOP commercial catalysts were used to evaluate the relative hydrogenation activity. At base pressure, studies were conducted at five temperatures and three space velocities, while at 500 psig above base pressure studies were carried out at three temperatures and three space velocities. Three distinct feedstocks were studied. Two sets of processing conditions were employed to catalytically crack each of these feedstocks.

A-026

Coal Liquefaction/Upgrading H-Coal

DeRosset, A. J., Tan, G., Hilfman, L., UOP, Inc., Des Plaines, Illinois "UPGRADING DISTILLATES FROM COAL LIQUEFACTION". Annual Report for the Period January 78 - January 79; prepared for DOE, contract No. EF-77-C-01-2566, May 1979 (Upgrading of coal liquids).

Abstract: The annual report summarizes the first years of experimental work on the H-Coal distillates. Detailed results are given in the Interim Reports. The complete program will also include results from processing EDS and SRC II distillates. These results will be presented in subsequent Interim Reports and the Final Report.

A-027

Coal Liquefaction/H-Coal

Bernard, R. F., Hydrocarbon Research, Inc., Lawrenceville, N. J., "COAL CLEANING EFFECTS DURING H-COAL CATALYTIC LIQUEFACTION OF A WESTERN KENTUCKY COAL". Final Report, prepared for DOE, December 1978, Contract No. EW-78-C-22-0265; 71 pages.

Abstract: Two H-Coal bench scale liquefaction tests were performed to compare the hydroliquefaction behavior of two Kentucky No. 11 coals from the same mine: a run-of-mine coal with a high ash content and a deep-cleaned coal. The deep-cleaned coal exhibit greater coal conversion and greater residual oil yield than the run-of-mine coal. Detailed operating data with properties.

A-028

Coal Conversion/H-Coal

Tan, G., DeRosset, A. J. UOP, Inc., Des Plaines, Illinois "HYDROCRACKING OF H-COAL PROCESS DERIVED GAS OILS" Interim Report of "Upgrading of Coal Liquids" prepared for the DOE, Contract No. EF-77-C-01-2566 November 1978, 133 pages.

Abstract: Evaluation of applying commercial UOP hydrocracking processes to conversion of H-Coal atmospheric bottoms in bench scale continuous tests. Catalysts, process conditions and reactor sequence were varied to produce either gasoline, or environmentally acceptable No. 2 fuel oil.

A-029

Coal Liquefaction/Lummus Process

Schinelles, H. D., Long, R. H., The Lummus Company, Bloomfield, N.J. "DEVELOPMENT RESEARCH PROGRAM FOR CLEAN INDUSTRIAL AND TRANSPORTATION FUELS FROM COAL" Milestone Report on Solvent - Sufficiency with Equilibrium Solvent & Catalyst Life Testing, Period August 1977-July 1978. Prepared for the DOE, Contract No. EX-76-C-01-2514 February 1979, 58 pages.

Abstract: Development program to establish conditions of optimum and reliable operability for the "Lummus Clean Fuel From Coal" (LCFFC) Process. The information is generated in two subtasks covering - Solvent self-sufficiency with equilibrium solvent and catalyst life study.

A-030-M

Coal Conversion/Clean Coke Process

USS Engineers & Consultants, Inc.; Pittsburgh Pennsylvania. "CLEAN COKE PROCESS: PROCESS DEVELOPMENT STUDIES, Final Report: Volume III; Part 2 Process Economics" prepared for DOE, December 1978, 35 pages.

Abstract: Economic evaluation of clean coke plant to process 12.43×10^6 tons p.a. formcoke pellets, 1.5×10^6 tons of chemical products and more than 33×10^{12} Btu of

liquid fuel. Total investment $\$1.75 \times 10^9$, with coke \$150 per ton, chemicals \$256 per ton and \$2.5 per million Btu, a 14 percent return on investment was projected.

A-031

Coal Conversion/Clean Coke Process

USS Engineers & Consultants, Inc., Pittsburgh Pennsylvania. "CLEAN COKE PROCESS: PROCESS DEVELOPMENT STUDIES Final Report: Volume III; Part 1, Final Process Design & Economics" prepared for DOE, December 1978, 152 pages.

Abstract: Detailed process description, with material balance for a commercial plant, charging 8.9×10^6 tons p.a. (Illinois No. 6). No product analysis.

A-032

Coal Liquefaction/Dow Process

Moll, N. G., Quardere, G. J., Dow Chemical, Midland, Michigan "THE DOW COAL LIQUEFACTION PROCESS" from Chemical Engineering Progress, November 1979, 5 pages.

Abstract: Dow coal liquefaction process description with some characteristic data of the products, catalyst and feed. Bench-scale size of Process!

A-033

Coal Liquefaction/Lignite With Synthesis Gas

Appell, Miles, Illig, Moroni, Steffgen; PETC Pittsburgh Pennsylvania "COAL LIQUEFACTION WITH SYNTHESIS GAS" prepared by Pittsburgh Energy Technology Center for DOE PETC/TR-79/1. Published September 1979, 60 pages.

Abstract: Bench scale research and process development in batch autoclaves to liquefy lignite coal with synthesis gas. Extensive coal analysis and catalyst investigation, little product analysis and information.

A-034-P

Coal Conversion/Lignite Pyrolysis

Steinberg, M., Fallon P., Brookhaven National Laboratory, Upton, N. Y. "FLASH HYDROLYSIS OF COAL" in Chemical Engineering Process; p. 63-66, June 1979.

Abstract: Hydrolysis of North Dakota lignite. Experimental results indicate that the principal liquid yields are benzene and aromatic oil; gaseous yields are methane and ethane.

A-036

Coal-Liquefaction/H-coal Analysis

Becker, M. et al, Mobil Research and Development Corporation, Paulsboro, New Jersey. "ANALYTICAL STUDIES FOR THE H-COAL PROCESS" Milestone Report for Compositional Analysis of Illinois No. 6 Syncrudes by Mobil Research and Development Corporation, New Jersey (co-authors Bendoraitis, J. G., Bloch, M. G., Cobal A. V., Callen, R. B., Green, L. A., Simpson, L. A.) prepared for the DOE contract No. EF-77-C-01-2676, 1979 (?).

Abstract: Analysis of H-Coal Syncrude product streams of Illinois No. 6 coal, have been obtained from the Trenton, New Jersey Process Development Unit of Hydrocarbon Research, Inc. Physical and Chemical Properties, Trace Metal Content, and comparison with equivalent Petroleum of the three fractions: Naphtha, Light Fuel Oil, Heavy Fuel Oil.

A-037

Tan, G. DeRosset, A. J., UOP Inc., Des Plaines, Illinois. "UPGRADING OF COAL LIQUIDS" "HYDROTREATING AND REFORMING EDS PROCESS DERIVED NAPHTHAS". Interim Report, prepared for the DOE, February 1979.

Abstract: Investigation of Naphtha from Exxon Donor Solvent process and processing in pilot plants into 100 octane motor fuel by conventional refinery processes, using commercial UOP catalysts.

A-038

Coal Liquids/Upgrading to GT Fuel

Bendoraitis, J. G. et al, Mobil Research and Development Corporation, Paulsboro, New Jersey. "UPGRADING OF COAL LIQUIDS FOR USE AS POWER GENERATION FUELS". Phase I Report, January 1976, prepared for the Electric Power Research Institute, No. RP 361-1.

Abstract: Study on upgrading three coal liquids for use as gas turbine fuel. SRC and H-Coal from Illinois No. 6 coal and synthoil from West Virginia coal. The areas of work included the analytical characterization of coal liquids, the compatibility with selected petroleum fuels, estimation of potential turbine fuel specifications for coal liquids, and some exploratory process studies.

A-039

Coal Liquefaction, SRC

Johanson, E., Hydrocarbon Research, Inc., Trenton, New Jersey. "SOLVENT REFINING OF ILLINOIS NO. 6 AND PITTSBURGH NO. 8 COALS". Final Report, June 1975, prepared for EPRI Project No. RP 389.

Abstract: Program of three continuous bench unit runs providing results of the effect of backmixing in the contacts during SRC operations. The runs were performed with Illinois No. 6 and a low sulfur and high sulfur Pittsburgh Seam coal.

A-040 (Microfiche)

U.S. Dept. of the Interior, Bureau of Mines, "50,000 - BARREL - PER-DAY LIQUID FUELS PLANT, H-COAL PROCESS - WYODAK COAL, AN ECONOMIC ANALYSIS", Prepared for ERDA, March 1976.

Abstract: Economic evaluation of an integrated plant sized and designed to produce 50,000 BPSD of Liquid product from Wyodak ROM coal. The process design basis and yields for this plant were taken from work done by Hydrocarbon Research INC.

A-041

Synfuels/Properties

Reynolds, T. W., Niedzwiecki, R. W., Clark, J. S., NASA Lewis Research Center. "LITERATURE SURVEY OF PROPERTIES OF SYNFUELS DERIVED FROM COAL". Preliminary edition, prepared for DOE No. EG-77-A-01-2593, February 1979.

Abstract: This report is an interim literature survey of the properties of syn-fuels for ground-based gas-turbine applications, compiled to December 1977. Four major concepts for converting coal into liquid fuels are described: solvent extraction, catalytic liquefaction, pyrolysis, and indirect liquefaction. Data on full-range syncrudes, various distillate cuts, and upgraded products are presented for fuels derived from various processes, including H-Coal, Synthoil, Solvent-Refined Coal, COED, Donor Solvent, Zinc Chloride Hydrocracking, Co-Steam, and Flash Pyrolysis. Some typical ranges of data for coal-derived low-Btu gases are also presented.

A-043 (Microfiche)

Synthetic Fuels/Aviation Turbines

C. D. Kalfadelin, Exxon Research and Engineering Company, Linden New Jersey. "EVALUATION OF METHODS TO PRODUCE AVIATION TURBINE FUELS FROM SYNTHETIC FUELS" May 76, NTIS AD-A036190.

Abstract: Engineering planning study of the effect of processing shale in a refinery processing both shale oil and petroleum to a full produced shale including jet fuel. The EXXON RESCUE Linear Program for refinery planning was used for the analysis. Base case studies for Paraho, Tosco and Garrett shale oil was made.

A-044 (Microfiche)

Schmid, B. K., Koenig, J. C., Jackson, D. M., Gulf Mineral Resources Co., "ECONOMIC AND MARKET POTENTIAL FOR SRC II PRODUCTS", Presentation at the 6th Annual International Conference on Coal Gasification, Liquefaction and Conversion to Electricity, University of Pittsburgh, PA, July/August 1979.

Abstract: Market and selling price of SRC II fuels based on fourth quarter 1978 prices. It is expected that SRC II fuel oil will become competitive with petroleum-derived fuels within the next decade. For the longer term the major growth opportunity for SRC II fuel oil is expected in the generation of electric power.

A-045 (Microfiche)

Nongbri G. "SOLVENT REFINING OF WEST KENTUCKY 9-14 COAL" May 1977, Hydrocarbon Research, Inc., Trenton, New Jersey. NTIS EPRI-AF-499.

A-047 (Microfiche)

Lewis, H. E., Weber, W. H., Hooks, H. W. "SRC PROCESS OPERATION OF SRC PILOT PLANT AT WILSONVILLE, ALABAMA". Annual Report January-December 1976, Catalytic Inc., Wilsonville, Alabama. NTIS EPRI-AF-585.

A-048 (Microfiche)

Zahnsteches, L. W., C. W. Chen, S. Bernstein. "CLEAN DISTILLATE FUELS PILOT PLANT CONCEPTUAL STUDY", Final Report, April 1978, Foster Wheeler Energy Corporation, Livingston, New Jersey; NTIS EPRI-AF-622.

A-049 (Microfiche)

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A-050 (Microfiche)

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A-051 (Microfiche)

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A-052 (Microfiche)

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A-053 (Microfiche)

Dabkowski, M. J., R. H. Heck, T. R. Stein, "ECONOMIC SCREENING EVALUATION OF UPGRADING COAL LIQUIDS TO TURBINE FUELS", Final Report, March 1978, Mobil Research and Development Corporation, Paulsboro, New Jersey, NTIS EPRI-AF-710.

A-054 (Microfiche)

Lewis, N. E., W. H. Weber, G. B. Usnick, W. R. Hollenack, H. W. Hooks, "SRC PROCESS OPERATION OF SRC PILOT PLANT AT WILSONVILLE, ALABAMA", Annual Report January-December 1978, Southern Company Services, NTIS EPRI-AF-867.

A-055 (Microfiche)

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A-056 (Microfiche)

Deno, M. C., B. a. Greigiger, A. D. Jones, W. G. Rakitsky, S. G. Stroud, "COAL STRUCTURE AND COAL LIQUEFACTION", Final Report, May 1979, Pennsylvania State University, NTIS EPRI-AF-960.

A-057 (Microfiche)

Bertolacini, R. J., L. C. Gutberlet, D. K. Kim, K. k. Robinson, "CATALYST DEVELOPMENT FOR COAL LIQUEFACTION", Final Report, January 1979, Amoco Oil Company, Naperville, Illinois, NTIS EPRI-AF-1084.

A-058 (Microfiche)

Sage, W. L., W. Downs, P. L. Cioffi, "CHARACTERISTICS OF SOLVENT REFINED COAL: DUAL REGISTER BURNER TEST", Final Report, January, 1978, Babcock and Wilcox Company, Alliance, Ohio, Research Center, NTIS EPRI-FP-628.

A-059 (Microfiche)

Downs, W., A. J. Kubasco, "CHARACTERIZATION AND COMBUSTION OF SRC II FUEL OIL", Final Report, June 1979, Babcock and Wilcox Company, Alliance, Ohio, NTIS EPRI-FP-1028.

A-060 (Microfiche)

Dickson, E. M., R. V. Steele, E. E. Hughes, "IMPACTS OF SYNTHETIC LIQUID FUEL DEVELOPMENT: ASSESSMENT OF CRITICAL FACTORS", Vol II analysis 76-129/2 SRI Project EGU-3505; Stanford NTIS ERDA-76-129/2.

A-061 (Microfiche)

Dickson, Yobroff, Kroll, White, Walton, Ivory, Fullen, Weisbecker, Hays, "SYNTHETIC LIQUID FUELS DEVELOPMENT: ASSESSMENT OF CRITICAL FACTORS", May 1977, Stanford Research Institute, Menlo Park, California, NTIS ERDA-76/129/3.

A-062 (Microfiche)

Steele, R. V., K. J., Sharma, E. M. Dickson, "SYNTHETIC LIQUID FUELS DEVELOPMENT: ASSESSMENT OF CRITICAL FACTORS", Volume IV, May 1977, Stanford Research Institute, Menlo Park, California, NTIS ERDA-76-129/4.

A-063, B-015 (Microfiche)

Gallagher, J. P. et al, "SYNTHESIS AND ANALYSIS OF JET FUEL FROM SHALE OIL AND COAL SYNCRUDES", November 1976, Atlantic Richfield Company Harvey, Illinois, NTIS N77-12230.

A-064 (Microfiche)

Dunbar, D. N., et al, "COMPUTER MODEL FOR REFINERY OPERATIONS WITH EMPHASIS ON JET FUEL PRODUCTION, VOLUME 3, DETAILED SYSTEMS AND PROGRAMMING DOCUMENTATION", Final Report, June 1978, Jordan Associates, New York, NTIS: N78 25235.

A-065 (Microfiche)

Lichtblau, J. H., "AVAILABILITY OF LIQUID FUELS FROM CONVENTIONAL SOURCES FOR ELECTRIC UTILITY GAS TURBINES 1975-1985", Final Report, May 1977, California University, Livermore, Lawrence Livermore Laboratory, NTIS: TID-27648.

A-066 (Microfiche)

"PROPOSED SYNTHETIC FUELS COMMERCIAL DEMONSTRATION PROGRAM FACT BOOK", March 1976
ERDA, NTIS TID-27777.

A-067

Coal Liquefaction/Properties

Smithe, N. K., S. H. Lee-Bachthold, W. D. Good, Bartlesville Energy Technology Center, "THERMODYNAMIC PROPERTIES OF MATERIALS DERIVED FROM COAL LIQUEFACTION", Report No. DOE/BETC/TPR 79-2, January 1980.

Abstract: Measuring of enthalpies of combustion and heat capacities of well-defined fractions of coal derived materials. The sets of fractions came from five sources and four processes.

A-068

Rogers K. A., R. F. Hill, ESCOE, Washington D.C., "COAL CONVERSION COMPARISONS", Report by the Engineering Societies Commission on Energy, Inc. for DOE, July 1979.

Abstract: This ESCOE Report examines technologies for producing substitute fuels (Synfuels) from domestic coal. Techniques for comparison are developed and applied to fourteen coal conversion processes.

The conclusion is made that many processes are ready for commercial demonstration, but at costs greater than for conventional petroleum fuels. All product costs in the report are based on the recently published ESCOE costing quicklines using both utility and private venture financing. All costs are in mid-1979 dollars.

A-069

Ralph M. Parsons Corp., "LIQUEFACTION TECHNOLOGY ASSESSMENT", Final Report with Union Carbide Corp. for the DOE, July 1978.

Abstract: Result of an investigation of coal liquefaction processes that are under development.

A-070

Bonnes and Moore Associates, Inc., Houston, Texas, "ECONOMIC EVALUATION OF COAL BASED SYNTHETIC CRUDE", Prepared for ERDA, April 1975.

Abstract: The study establishes coal-based synthetic crude oil as a raw material to all types of petroleum refineries. Comparison between syncrude cases and non-syncrude cases yielded the economic results required for evaluation of syncrude's worth to the refining industry.

A-071

Bendoraitis, J. G. et al, Mobil Res. and Dev. Corp., Paulsboro, N. J., "UP-GRADING OF COAL LIQUIDS FOR USE AS POWER GENERATION FUELS", Prepared for EPRI, January 1976.

Abstract: Phase I of a study on upgrading coal liquids from SRC, H-Coal and Synthoil processes. Analytical characterization of coal liquids and comparison with petroleum fuels.

A-072

Stein, T. R., et al, Mobil Res. and Dev. Corp., Paulsboro, N. J., "UPGRADING OF COAL LIQUIDS FOR USE AS POWER GENERATION FUELS", Annual Report, December 1978. (Co-authors: Cabal, Callen, Dabkowski, Heck, Simpson, Shih)

Abstract: Residual coal liquids were hydroprocessed in a fixed bed hydroprocessing unit. Test-runs were performed with H-Coal and SRC syncrudes.

A-073

Mulik, P. R., et al, Mobil Res. and Dev. Corp., Paulsboro, N. J., "AN INVESTIGATION OF THE UTILIZATION OF COAL-DERIVED LIQUID FUELS IN A COMBUSTION TURBINE ENGINE", Annual Report, December 1978, Prepared for EPRI. (Co-authors: Singh, Chamberlin, Duzubay, Spengler, Paulukonis)

Abstract: A series of four SRC-liquids and three H-Coal liquids were evaluated in an existing pressurized combustor passage. The liquid fuels varied in quality from raw process solvent to coal liquids that were upgraded via severe hydroprocessing.

A-074

NASA/Lewis, "FUEL PROPERTIES", from "Literature Survey of Properties of Syn-fuels Derived from Coal".

Abstract: Schematics of coal conversion processes and description.

A-075 (Microfiche)

Greskovich, E. J., Air Products and Chemicals, Inc., Allentown, PA., "CHEMICAL CHARACTERIZATION, HANDLING, AND REFINING OF SRC TO LIQUID FUELS", Final Report, June 1975 - June 1976. September 1977, FE-2003-27.

Abstract: A bibliography relating to the characterization and refining of solvent-refined coal and coal-derived liquids has been prepared. Analyses and characterization tests of Wilsonville and Ft. Lewis SRC products show that they meet or exceed the low-ash, low-sulfur specifications. No significant inter- or intra-drum variations in composition occurred. Various analytical methods have been evaluated for use of SRC material are discussed: Agglomeration, sintering at or above 200°F., clogging of screens, consolidation and packing, grinding behavior, plugging burners, storage behavior, weathering, adhesion in pneumatic transport, etc. Finally, a unit is being constructed for desulfurization, denitrogenation and hydrocracking of SRC with solvent. Results of initial runs are reported.

A-076 (Microfiche)

Aczel, T. et al, Exxon Research and Engineering Co., Baytown, Tex., "CHEMICAL PROPERTIES OF SYNTHOIL PRODUCTS AND FEEDS", Final Report, Part 5, September 1976, MERC-8007-1 (Pt. 5)

Abstract: Tables of the chemical composition of coal extracts and coal liquid products from the synthoil process are presented based on chemical analysis or mass spectrometry of samples fractionated in various ways. (Extraction in various solvents, gas chromatography, etc.)

A-077 (Microfiche)

Holmes, S. A., et al, Bureau of Mines, Bartlesville, OK., Bartlesville Energy Research Center, "CHARACTERIZATION OF COAL LIQUIDS DERIVED FROM THE H-COAL PROCESS", November 1976, BERC-RI-76-10.

Abstract: Compositional data of coal liquid products derived from the H-Coal process were obtained. Two overhead products (one from the fuel oil mode of operation and the other from the syncrude mode of operation) were prepared by Hydrocarbon Research, Inc. from Illinois No. 6 coal. The compositional data of these products are tabulated, and characteristics of the materials are discussed. Separation and characterization methods, with slight modification, as developed by the Bureau of Mines - API Research Project 60 for characterizing heavy ends of petroleum, were successfully used in analyzing coal liquid distillates within the boiling range 200° to 540° C. Distillates boiling below 200° C. were separated and analyzed using chromatographic and spectral techniques.

A-078 (Microfiche)

Aczel, T., et al, Exxon Research and Engineering Co., Baytown, Tex., "CHEMICAL PROPERTIES OF SYNTHOIL PRODUCTS AND FEEDS", Feb. 1977, MERC-8007-1 (Summ.)

Abstract: Data obtained on the chemical properties of synthoil products and feeds are summarized. Emphasis is placed on the overall characterization, the individual compounds and carbon number homologs determined in the oil fractions, the structural parameters calculated for the asphaltene fractions and the possible correlations between product composition and processing conditions, the detailed data are published in a five volume final report entitled "Chemical Properties of Synthoil Feeds and Products" are extremely complex materials that can, however, be characterized in detail with the proper analytical methodology. The scope of the characterization can be gauged to the immediate or longer range process requirements. Significant correlations exist between product composition and processing conditions. The main effects of the process, apart from the increase in the oil fractions, include a drastic decrease in the sulfur content and a significant increase in hydroaromatic components.

A-079 (Microfiche)

Schultz, H., et al., Energy Research and Development Admin., Pittsburgh, PA. Pittsburgh Energy Research Center, "DISTRIBUTION OF SOME TRACE ELEMENTS IN THE 1/2 TON PER DAY SYNTHOIL PROCESS DEVELOPMENT UNIT", Feb. 1977, PERC/RI-77/2.

Abstract: The synthoil 1/2 - ton per day process development unit (PDU) was carefully sampled in an attempt to determine the distribution. In all process streams, of several trace elements which enter the PDU in the feed coal, results for six metals (Chromium, Copper, Manganese, Nickel, Cadmium, and Lead) indicate that the sampling procedures and analytical methods described give good material balances for the PDU and three subunits within the PDU. The levels of all six trace elements were lower in the product oil than in the feed coal. The centrifuge residue was the primary sink for the trace elements.

A-080 (Microfiche)

Derosset, A. J., et al, UPO, Inc., Des Plaines, Ill., "CHARACTERIZATION OF COAL LIQUIDS", March 1977, FE-2010-09.

Abstract: The objective of this investigation is to evaluate the process-ability of the primary products of coal liquefaction generated by three ERDA sponsored processes: Synthoil, Solvent refined coal (SRC), and H-Coal. The study entails actual bench scale processing of coal liquids and an in-depth analytical characterization of charge and product streams. The results are intended to indicate the nature and degree of possible upgrading of primary coal liquids using technology now available in the petroleum refining industry. Six primary coal liquids were filtered and hydrotreated under commercial conditions. Using a fixed bed of commercial catalyst. These included synthoil, H-Coal Hydroclone underflow, and four SRC process streams--SRC filter feed, SRC filtrate and solvent refined coal itself, both neat and cutback with process solvent. In all cases catalytic hydrotreating was able to substantially eliminate sulfur and benzene insoluble matter. A 90% reduction of Heptane-insoluble matter and 80% reduction in N content could be achieved with SRC and H-Coal liquids. Catalyst stability was affected by metals and particulates in the feed. None of the products, as received, can be considered an acceptable feedstock to a conventional fixed bed hydrotreating unit. The ash remaining will agglomerate with the solid catalyst pellets and shorten catalyst life. Two of the hydrotreated coal oils, synthoil and SRC, were further processed under commercial conditions over a fixed bed of commercial hydrocracking catalyst. Catalyst stability was unsatisfactory when the total upgraded products were processed. An asphaltene-free vacuum gas oil derived from hydrotreated synthoil responded satisfactorily to hydrocracking.

A-081 (Microfiche)

Droege, J. W., et al, Rattelle Columbus Labs., Oh., "PHYSICAL PROPERTIES OF SYNTHOIL PRODUCTS", Final Technical Report, July 6, 1977, BMI-010405.

Abstract: Measurements of viscosity and electrical properties have been made from synthoil product oils and preheater specimens at elevated temperatures and pressures. These properties were measured in a single apparatus designed for the purpose. Viscosities were measured by a modified falling-cylinder method. A known force was applied to move the bob axially while the rate of motion was measured, both by magnetic coupling across the pressure boundary. The bob was insulated from the autoclave and used as an electrode for electrical measurements. The product oils and preheater specimens showed the viscous properties of bingham fluids. The yield stress was small compared to shear stress observed in the measurement

and encountered in pumping. Relationships were developed between the pressure and temperature coefficients of viscosity and between the viscosity and electrical resistivity. Both temperature and pressure coefficients of both viscosity and resistivity were found to be high for high properties with time were observed for product oils. At the higher temperatures required for preheater specimens, an increase in viscosity with time was observed for some, but not for all specimens.

A-082 (Microfiche)

Briggs, D. E., et al, Michigan Univ., Ann Arbor, MI., "PHYSICAL AND CHEMICAL BEHAVIOR OF LIQUEFIED COAL IN SOLIDS SEPARATION", Quarterly Report, April-June 1977, July 1977, FE-2550-3.

Abstract: 4- α , Ω bis-(Hydroxyphenyl) alkanes and 4- α , Ω dipyrldyl or diquinolyl alkanes were synthesized and purified to yield crystalline solids to provide model asphaltene components. These compounds could account for the middle-field portion of asphaltene NMR spectra. Neutron activation was used to measure the metal contents of liquefied coal residues, extracts and GPC fractionated samples. Repairs and modifications to the filtration equipment were completed and recalibration of differential pressure instruments begun. The design of a sample holder and cell for small angle x-ray scattering experiments to measure the size-configuration of asphaltene colloids was completed and cell manufacture begun. Experimental equipment to measure the electrical conductivity and dielectric constants of asphaltene solutions was calibrated. Adsorption equilibrium data between an asphaltene in nitrobenzene and alumina were obtained. Asphaltene adsorption from pyridene onto alumina at equilibrium concentrations up to 25 weight percent were taken. Streaming potential measurements were begun for the flow of asphaltene solutions through fixed beds. The effect of drying and heating on the viscosity of an asphaltene fraction was examined.

A-083 (Microfiche)

Blatisberger, R. J., et al, Univ. of No. Dakota, Grand Forks, Mont., "COMPARISON OF SOLVENT REFINED LIGNITE WITH SOLVENT REFINED BITUMINOUS COALS", October 1977, FE-2211-7.

Abstract: Comparison of laboratory deashed samples of solvent refined lignite, subbituminous and bituminous coals on the basis of gross combustion analysis, acid and basic titers, molecular weight, nuclear magnetic resonance, ultraviolet and electron spin resonance spectra including various derived parameters indicated that there is relatively little difference between the range of values for lignite and bituminous coal derived solvent refined products. The probability that coal nitrogen content is reflected in the solvent refined product was noted.

A-084 (Microfiche)

Broccoardo, M. R., et al, Johns-Manville Sales Corp., Denver, Colo., "VISCOSITY, SUSPENDED SOLIDS, AND FILTRATION STUDIES OF LIQUEFIED COALS", December 1977, EPRI-AF-614.

Abstract: Studies were made of viscosity, vapor pressure, suspended solids characteristics, and filtration properties of several liquefied coals. Viscosities and vapor pressures were measured at temperatures up to approx. 370° C. (700° F.) with a synatrol viscosity instrument. The effects of solvent dilution and suspended solids on viscosity were also studied. Residual gases formed by holding samples of liquefied coal at elevated temperatures followed by cooling were analyzed on a gas chromatograph. Mineral and chemical analyses were made of suspended solids. Particle size analyses were made of pyridine insolubles using light scanning electron microscopes and computerized particle size analysis techniques. Median particle sizes determined for several coals were approximately 0.5 micrometer compared to average particle sizes of 1.6 to 8 micrometers as measured by particle counters. A laboratory filter capable of operating at up to 400 PSIG and 700° F was designed and constructed. The effects of temperature, differential pressure, viscosity, solvent addition, and body feed addition on filtration rates were studied. Theoretical calculations of filtration data were made to show average cake resistance, cake compressibility, constant rate cycle lengths for different filtration rates, and rotary drum pressure precoat filtration rates at different drum rotation speeds.

A-085 (Microfiche)

Sturm, G. P., Jr., et al, Dept. of Energy, Bartlesville Okla. Bartlesville Energy Research Center, "CHARACTERIZATION OF A COLSTRIP COAL LIQUID DERIVED FROM THE ZINC CHLORIDE HYDROCRACKING PROCESS", May 1978, BERC/RI--78/4.

Abstract: In continuing series of characterization studies, the Bartlesville Energy Research Center characterized two distillates and a residue fraction derived from a colstrip coal liquid produced by the Conoco Coal Development Co. Molten zinc chloride catalytic liquefaction process. Procedures established in earlier work on the heavy ends of petroleum, were slightly modified and applied to these materials. The techniques include several applications of chromatography and instrumental analyses. Although only 40% of the original coal liquid was submitted for analyses, the results were unique in that the portion of the coal liquid analyzed contained a significantly higher amount of monoaromatics as compared to other liquids characterized by use of these procedures.

A-086 (Microfiche)

Robinson, R. L., Jr., Oklahoma State Univ., Stillwater, School of Chemical Engineering, "PHASE EQUILIBRIUM AND VOLUMETRIC PROPERTIES OF COAL-DERIVED FLUIDS", 1978, FE-2278-8

Abstract: The thermodynamic properties of fluid mixtures are required for accurate design of equipment in which such fluids are stored, transported or separated. The basic goal of the present project is to obtain data for components and conditions where information is currently lacking. The mixtures studied will be chosen to approximate those which occur in the processing of coal-derived fluids. The research is divided into three major areas as follows: 1) Design, construction and operation of a Eurnett-type apparatus for measurement of volu-

metric properties (pressure-volume-temperature-composition relationship) of gases, and measurement of the properties of the pure substances and selected mixtures of H₂, CO, CH₄ and H₂O at conditions from ambient to 800° F and 2,000 PSIA; 2) Design, construction and operation of a variable-volume, windowed phase-equilibrium cell capable of operation to 800° F. and 2,000 PSIA, and measurement of vapor-liquid equilibrium in mixtures composed of selected light hydrocarbons/heavy aromatic hydrocarbons/water; and 3) Testing and/or development of prediction methods for estimation of volumetric properties and phase equilibrium in mixtures of the type studied experimentally, and presentation of results in format suitable for use in process design calculations.

A-087 (Microfiche)

Griest, W. H., et al, Oak Ridge National Lab., Tn., "RELATIVE CHEMICAL COMPOSITION OF SELECTED SYNTHETIC CRUDES", 1978, CONF-781150-4.

Abstract: A knowledge of the composition of synthetic crudes can provide an important input into the assessment of occupational exposure monitoring requirements for the coal conversion and oil shale industries. This paper summarizes comparative compositional studies of coal-and shale-derived crude oils with petroleum crude oils as a reference point.

A-088 (Microfiche)

Downs, W., et al, Babcock and Wilcox Co., Alliance, OH. Research Center, "CHARACTERIZATION AND COMBUSTION OF SRC II FUEL OIL", Final Report, June 1979, EPRI-EP 1028.

Abstract: This report deals with an experimental evaluation of the SRC II process's principal product, solvent refined coal fuel oil (SRC fuel oil), for use with commercial scale steam generating equipment. The purpose was to identify problems, if any, associated with handling, storing, pumping, and burning SRC fuel oil. Detailed fuels characterization analyses were performed and compared to petroleum distillate products. An industrial boiler rated at a steam flow of 45,000 LBS/HR was utilized for combustion tests. Modifications made to the boiler facility included connection of an existing air heater to supply combustion air at 400° F., revamping of the boiler controls to permit biasing of the fuel/air ratio, installation of a high pressure mechanical return flow pumping and atomization system, various gas and particulate analysis instrumentation. Combustion tests were performed with SRC fuel oil, No. 2 fuel oil, and No. 5 fuel oil. Operating variables included load, excess air, and burner register settings. The laboratory fuel analyses indicated that in most respects this SRC fuel oil sample behaved similarly to No. 2 fuel oil. The combustion test confirmed that SRC fuel oil burns similarly to No. 2 fuel oil with one notable exception, NO_x emissions were substantially higher than for either the No. 2 or No. 5 fuel oils. It was concluded that SRC fuel oil will require the application of NO_x combustion control techniques to meet the proposed new source performance standards of 0.5 pound NO_x/million Btu when burned in power boilers equipped with wall-mounted burners.

A-089 (Microfiche)

Che, S. C., et al, Occidental Research Corp., LaVerne, CA, "PROPERTIES OF COAL LIQUIDS PRODUCED BY THE OCCIDENTAL FLASH PYROLYSIS PROCESS", Nov. 15, 1976, CONF-760885.

Abstract: A discussion is presented on the liquids prepared by Flash Pyrolysis of Coal. The company has had a process to accomplish this under development for several years. Some background information on the process is given followed by a discussion of the tars prepared and a comparison of them with coal tars from two other pyrolysis approaches. Pyrolysis of coal is analogous to distillation of crude petroleum in that coal is separated into fractions.

A-090 (Microfiche)

Fruchter, J. S., et al, Battelle Pacific Northwest Labs., Richland WA, "HIGH PRECISION TRACE ELEMENT AND ORGANIC CONSTITUENT ANALYSIS OF OIL SHALE AND SOLVENT - REFINED COAL MATERIALS", Nov. 1976, BNWL-SA-6001.

Abstract: The application of a number of sensitive and precise methods for the determination of trace elements, heavy element species and organic compounds in materials from an oil shale research retort process and from a solvent-refined coal pilot plant operation are discussed. The methods were chosen both for their sensitivity, and also for their relative freedom from interference effects. Coal liquids contain much higher concentrations of aromatic compounds, including Polynuclear Aromatic Hydrocarbons (PNA's). A larger relative fraction of the PNA's in shale oil are alkyl substituted. Coal liquids are also considerably higher in Phenols (28 percent) than is shale oil (2 percent). N-Heterocyclics are present in higher concentration (greater than 8 percent) in shale oil due to the high nitrogen content of the raw shale. Hydroaromatics are common in coal liquids but negligible in shale oil. Inorganic elements and speciation measurements indicate significant amounts of the toxic heavy elements HG, AS, ZN, and SE in effluent oil water and gas streams. In addition, the process water contains significant CO, BR, SB, and U. Raw oil shale is highly enriched in SE, AS, and SB and somewhat enriched in U, PB, CS, HG, and ZN. Solvent-refined coal liquids were found to be relatively low in most trace elements. The majority of trace elements are concentrated by the process into the mineral residue. Only BR and HG are not depleted in solvent-refined coal. Other trace elements still remaining in significant amounts are U, TA, CR, and ZN.

A-091 (Microfiche)

Broccardo, M. R., et al, Johns-Manville Sales Corp., Denver, Colo., "VISCOSITY SUSPENDED SOLIDS, AND FILTRATION STUDIES OF LIQUEFIED COALS", Final Report, Dec. 1977, EPRI-AF-614.

Abstract: Studies were made of viscosity, vapor pressure, suspended solids characteristics, and filtration properties of several liquefied coals. Viscosities and vapor pressures were measured at temperatures up to approximately

700° F. The effects of solvent dilution and suspended solids on viscosity were also studied. Residual gases formed by holding samples of liquefied coal at elevated temperatures followed by cooling were analyzed. Mineral and chemical analyses were made of suspended solids. Particle size analyses were made of pyridine insolubles. Median particle sizes determined for several coals were approximately 0.5 micrometer compared to average particle sizes of 1.6 to 8 micrometers as measured by particle counters.

A-092 (Microfiche)

Filby, R. H., et al, Washington State Univ., Pullman, Nuclear Radiation Center, "SOLVENT REFINED COAL (SRC) PROCESS: TRACE ELEMENTS", Research and Dev. report No. 53; Interim report No. 26. Volume III. Pilot Plant Dev. work. Part 6. "The Fate of Trace Elements in The SRC Process for the Period August 1, 1974-July 31, 1976, April 1978, FE-496-T17.

Abstract: Results are presented of a study of the distribution and fate of 34 trace elements in the solvent refined coal process at the pilot plant located at Fort Lewis, Washington. Neutron activation analysis was used to determine TI, V, CA, MG, AL, CL, MN, AS, SB, SE, HG, BR, CO, NI, CR, FE, NA, RB, CS, K, SC, TB, EU, SM, CE, LA, SR, BA, TH, HF, TA, GA, ZR, and CU in feed coals, process solvent, solvent refined coal (SRC), mineral residues, wet filter cake, by-product solvents, process and effluent waters and by-product sulfur.

A-093 (Microfiche)

Walker, P. L., et al, Pennsylvania State Univ., University Park, "CHARACTERIZATION OF MINERAL MATTER IN COALS AND COAL LIQUEFACTION RESIDUES", Annual Report, Dec. 1978, EPRI-AF-832.

Abstract: One of the aims of this program is to characterize organic and mineral components of coals and coal liquefaction residual materials. Relationships are sought between composition and properties of these components and the behavior of specific coals during liquefaction processes. Characterization techniques utilized are optical and scanning electron microscopy, x-ray diffraction, fourier transform infrared (FTIR) spectroscopy and particle size analyses.

A-094 (Microfiche)

Spackmann, W., et al, Penn. State Univ., University Park, "CHARACTERISTICS OF AMERICAN COALS IN RELATION TO THEIR CONVERSION INTO CLEAN ENERGY FUELS", (Co-authors: Davis, Walker, Lovell, Essenhigh, Vastola, Given, Suhr), March 1978, NTIS: FE-2030-10-11.

A-095

Epperly, W. R., "EDS COAL LIQUEFACTION PROCESS DEVELOPMENT", Interim Report by Exxon Research and Engineering Comp., prepared for DOE, 4 reports, July/August/Sept. 1979.

Abstract: EDS commercial plant study design update. Revised onsite and off-site design basis - Illinois coal base case, and revised onsite/offsite design basis - Illinois coal market flexibility sensitive case.

A-096 (Microfiche)

TRW, Inc., McLean, VA., "ANALYSIS OF SRC PILOT PLANT DATA", Comparison of Wilsonville and Ft. Lewis plants, 1976, NTIS: RE-2213-T1.

A-097

SRC-II Demonstration Project, Phase Zero, Task Number 2, Deliverable Numbers 8 and 9, "CONCEPTUAL COMMERCIAL PLANT SUMMARY AND MARKET ASSESSMENT SUMMARY", The Pittsburgh & Midway Coal Mining Co., prepared for DOE, DE-AC05-78OR03055, July, 1979.

Abstract: This deliverable describes a Conceptual Commercial Plant (CCP) using the SRC-II Solvent Refined Coal process for the production of liquid and gaseous hydrocarbon synthetic fuels and by-products from coal. This plant is visualized as one of a number of "coal refineries" which would utilize domestic coal resources for the production of liquid fuels.

This report is Volume 1, Management Summary of Deliverable 8, Conceptual Commercial Plant for Phase Zero of the SRC-II Demonstration Project. Other volumes in this deliverable are:

- Volume 2 - Plant Description
- Volume 3 - Supporting Reports
- Volume 4 - Advanced Process Technology
- Volume 5 - Economic Analysis

This volume is a general summary of the information presented in the succeeding volumes and touches briefly on feedstocks, products, thermal efficiency, companion plants, future technology, environmental considerations, and projected capital and operating costs.

A-098

Petrie, T. W., Rhodes, W. J., Page, G. C., "ENVIRONMENT IMPACT OF SYNTHETIC FUELS DEVELOPMENT", Environmental Protection Agency and Radian Corp. in CEP June 1979.

Abstract: A status report of EPA's Synthetic Fuels Program, an effort to assess the effect of coal liquefaction and gasification processes on health and the ecology.

A-099

DeRosset, A. J., G. Tan, L. Hilfman, UOP, Inc., "UPGRADE COAL DERIVED DISTILLATES", Article in "Hydrocarbon Processing", May, 1979.

Abstract: Hydrotreating, hydrocracking, reforming and fluid catalytic cracking are tried on distillates from three coal liquefaction processes to explore possibilities for alternate fuels.

A-100

The Ralph M. Parsons Company, "LIQUEFACTION TECHNOLOGY ASSESSMENT", Final Report with Union Carbide Corp. for DOE, May 1979.

Abstract: This report describes the results of an investigation of coal liquefaction processes that are under development. The main objectives of the investigation were to:

- Survey coal liquefaction processes being developed;
- Review the status of development;
- Make comparative technical and economic evaluations of high potential processes.

From over 60 candidate processes, 33 were judged worthy of more extensive review.

A-101

Fluor Engineers and Constructors, Inc., "CONCEPTUAL DESIGN FOR ADVANCED COAL LIQUEFACTION COMMERCIAL PLANT", Final Report, Additional Studies, prepared for DOE, June 1978.

Abstract: Investigation of the two design options:

1. Utilize catalytic cracking in the refining sequence to produce gasoline from heavier coal derived liquids. Fluor's work had led to the selection of a refining sequence using hydrocracking to the exclusion of catalytic cracking in the base case.
2. Instead of following the original DOE specification that the facility should be self-sufficient with respect to its electric power needs, electric power should be purchased with the concomitant production and sale of additional SNG from fuel gas formerly used for power generation.

A-102

Exxon Research and Engineering Company, "EDS COAL LIQUEFACTION PROCESS DEVELOPMENT", Phase IIIB, Quarterly Technical Progress Report for the Period July - Sept., 1977, prepared for DOE.

Abstract: Content of this report:

- Laboratory Process Research and Dev., Liquefaction Process Research
- Engineering Research and Dev., Process Engineering and Cost Evaluation, Engineering Technology Dev.
- ECLP Project Management, Detailed Engineering, Procurement and Construction

A-103

Gold, H., J. A. Nardella, C. A. Vogel, "FUEL CONVERSION - AND ITS ENVIRONMENTAL EFFECTS", from Water Purification Ass., DOE and DPA Article in CEP, August 1979.

Abstract: Unless properly treated, water and air discharges contaminated with organic materials may pose the greatest potential threat to the environment from the emerging energy technologies.

A-104

Sass, A., Garrett Res. and Dev. Company, Inc., "THE GR & D COAL PYROLYSIS PROCESS", A Status Report; presentation at "Clean Energy from Coal" Session AICHE, 67th Annual Meeting, Dec. 1979.

Abstract: Report on the status of the GR & D program on the pyrolysis process to convert high sulfur coal into more marketable low sulfur synthetic fuels.

A-105-N

Hamshas, J. A., Terzian, H. D., Scotti, L. F. "CLEAN FUELS FROM COAL BY THE COED PROCESS" Research Triangle Park, N. C.; Symposium Proceedings: Environmental Aspects of Fuel conversion Technology, May 1974

Abstract: This paper considers ways in which the COED process can convert coal while satisfying environmental concern. Processing methods and flows are described for a commercial COED plant to process a high-sulfur, agglomerating coal and a low-sulfur coal.

A-106

Martin, G. B., W. S. Lanier, Research Triangle Institute. "COMBUSTION OF LIQUID SYNFUELS" Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology, April 1979.

Abstract: This paper summarizes the available information on the state-of-the-art emission control technology for the use of petroleum, shale, and coal-derived liquid fuels in stationary combustion sources.

A-107-N

Evans, F. "NIOASH PROGRAMS FOR EVALUATIONG AND CONTROL OF INDUSTRIAL HYGIENE HAZARDS IN COAL CONVERSION" Enviro Control Inc., Rockville, Maryland; Symposium Preceedings: Environmental Aspects of Fuel Conversion Technology IV, April 1979.

Abstract: This paper describes the techniques for sampling and analyzing in liquefaction and gasification plants and for the ultimate use of the data.

A-108-P

Ting, B. T. G., S. E. Manahan, "EFFECTS OF ORGANIC AND INORGANIC BINDING ON THE VOLATILIZATION OF TRACE ELEMENTS DURING COAL PYROLYSIS", Dept. of Chemistry, University of Missouri in "Environmental Science & Technology", December 1979.

Abstract: Volatilities were determined for eight environmentally important trace elements in coal subjected to pyrolysis in an inert atmosphere.

A-109-N

Martin, G. B., "NOx CONSIDERATIONS IN ALTERNATIVE FUEL COMBUSTION", Industrial Environmental Research Laboratory, prepared for U.S. EPA; Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology, December 1975.

Abstract: This paper concentrates on combustion and emission characteristics of alternate fuels, an area where information is still very limited. The topics covered include a summary of the most recent combustion data for both boiler and gas turbine systems and a presentation of some concepts that may have potential for controlling the formation of NOx and other pollutants in the combustion process.

A-110-N

Kang, C. C., J. Gendler, "CATALYST EVALUATION FOR DENITROGENATION OF PETROLEUM RESIDUA AND COAL LIQUIDS" Hydrocarbon Research Inc., prepared for EPA, August 1978.

Abstract: This report describes the results of a study of catalysts for denitrogenation of petroleum residua and coal liquids. The objectives were to evaluate some existing commercial catalysts for denitrogenation activity in petroleum residua and coal liquids and then to develop an improved catalyst for denitrogenation of heavy coal liquids. Under task two, commercial catalysts failed to reduce nitrogen content of a petroleum vacuum resid from 0.67 percent to the target of 0.3 percent.

A-111-N

Beychok, M. R., Consultant, Irvine, California, "ENVIRONMENTAL FACTORS IN PRODUCING SUPPLEMENTAL FUELS" in Hydrocarbon Processing, October 1975.

Abstract: This article based on the EPA's contracted study and presents an overall summary of environmental factors involved in producing various supplemental fuels. To provide a common basis of comparison, environmental factors are presented in terms of the Btu output of sales products and byproducts from each technology. The specific plants described in the study are: Naphtha SNG, LNG project, Crude oil SNG, SHALE OIL, Coal Sng Coal liquefaction, Methanol project.

A-112-N

Parker, C. L, D. J. Dykstra, "ENVIRONMENTAL ASSESSMENT, DATA BASE FOR COAL LIQUEFACTION TECHNOLOGY", Volume II, prepared for EPA by Hittmann Assoc., Inc., Columbia, Maryland, Contract No. 68-02-2;62, September 1978.

Abstract: Compositional analysis of synthoil, H-Coal and EDS products. Comparison of H-Coal products from Illinois No. 6 and Wyoming subbituminous coals.

A-113

See B-047

A-114 (Microfiche)

Wellman, P., "ECONOMICS OF THE H-COAL PROCESS", Ashland Oil, Inc., Kentucky, Report No. CONF-771203--, 1977.

Abstract: Liquefaction; Economics; Fuel Oils.

A-115 (Microfiche)

Dadkowski, M. J., R. H. Heck, A. V. Perrella, M. Schriener, Jr., T. R. Stein, "ECONOMIC SCREENING EVALUATION OF UPGRADING COAL LIQUIDS TO TURBINE FUELS", Mobil Research and Development Corp., Paulsboro, New Jersey, Process Research and Technical Service Division, Report No. EPRI-AF--710, March 1978.

Abstract: The objective of this study was to estimate the cost of upgrading coal liquids to turbine fuels.

A-116 (Microfiche)

Stein, T. R., A. V. Cabal, R. B. Callen, M. J. Dobkowski, R. H. Heck, C. A. Simpson, S. S. Shih, 'UPGRADING OF COAL LIQUIDS FOR USE AS POWER GENERATION FUELS', Mobil Research and Development Corporation, Paulsboro, New Jersey, Report EPRI-AF-873, December 1978.

Abstract: Residual coal liquids were hydroprocessed in a fixed bed hydroprocessing unit to upgrade them to high quality power generation fuels.

A-117 (Microfiche)

"OVERALL PLANT DESIGN DESCRIPTION (OPDO) COAL DERIVED LIQUID ELECTRIC POWER PLANT", General Electric Company, Schenectady, New York, Report No. FE--1806-24, July 1977.

Abstract: The Case C power plant fueled with coal-derived liquid (CLD) fuel generates 443,500 kW CF electrical power with an overall thermal efficiency of 48.66 percent based on higher heating value coal liquid to busbar.

A-118 (Microfiche)

Greskovich, E. J. "CHEMICAL CHARACTERIZATION, HANDLING, AND REFINING OF SRC TO LIQUID FUELS", Air Products and Chemicals, Inc., Allentown, PA, Report No. FE-2003-9, April 6, 1976.

Abstract: Progress in determining the chemical composition and chemical and physical properties of samples of solvent-refined coal is reported.

A-119 (Microfiche)

Sullivan, R. F., H. A. Frumkin, C. E. Rudy, H. C. Chen, "REFINING AND UPGRADING OF SYNFUELS FROM COAL AND OIL SHALES BY ADVANCED CATALYTIC PROCESS", Chevron Research Co., Richmond, California, Report No. FE--2315-15, July 1977.

Abstract: The objective of this program is to determine the feasibility and estimate the economics of hydroprocessing four synthetic fuels to distillate fuels, including high octane gasoline, using presently available technology. Process design studies based on pilot plant results indicate that it is desirable to hydrofine the whole shale oil to a nitrogen content of about 500 ppm and then to fractionate the product before conventional downstream processing to produce transportation fuels.

A-120 (Microfiche)

Sullivan, R. F., C. E. Rudy, C. D. Green, H. C. Chen, "REFINING AND UPGRADING OF SYNFUELS FROM COAL AND OIL SHALES BY ADVANCED CATALYTIC PROCESSES", Chevron Research Co., Richmond California, Report No. FE--2315-19, October 1977.

Abstract: The objective of this program is to determine the feasibility and estimate the economics of hydroprocessing four synthetic fuels to distillate fuels. The feedstocks include shale oil and three coal-derived synthetic crudes. The first feedstock is Paraho crude shale oil, produced in the indirectly heated mode.

A-121 (Microfiche)

Sullivan, R. F., C. E. Rudy, H. C. Chen, "REFINING AND UPGRADING OF SYNFUELS FROM COAL AND OIL SHALES BY ADVANCED CATALYTIC PROCESSES", Chevron Research Co., Richmond, California, Report No. FE--2315-28, July 1978.

Abstract: SRC-I and SRC-II, two different forms of solvent refined coal, have sharply contrasting characteristics as coal-derived feeds for conversion to transportation fuels. SRC-I process product is a relatively unattractive feed for conversion to distillate fuels using commercial fixed bed catalytic hydroprocessing technology.

A-122 (Microfiche)

Tan, G., A. Derosset, "UPGRADING OF COAL LIQUIDS", UOP, Inc., Des Plaines, Illinois, Report No. FE--2566-19, September 1978.

Abstract: Series flow hydrocracking of high nitrogen-containing Exxon Donor Solvent (EDS) process liquid to gasoline was continued at base pressure.

A-123

Derosset, A. J., G. Tan, L. Hilfman, "UPGRADING OF COAL LIQUIDS: UPGRADING DISTILLATES FROM COAL LIQUEFACTION, UOP, Inc., Des Plaines, Illinois, Report No. FE--2566-26, May 1979.

Abstract: Distillates from DOE-sponsored coal liquefaction products have been examined as potential feedstocks to commercial petroleum refining processes. The ultimate objective is to provide a new source of transportation fuels and environmentally acceptable fuel oils. Coal-derived naphthas from the H-Coal and Exxon Donor Solvent (EDS) processes have been hydrotreated and reformed in research pilot plants to 100 research octane number (RON) gasoline.

A-124 (Microfiche)

Diedl, F. J., A. J. Derosset, "DEASPHALTING, DEASHING, AND UPGRADING OF COAL LIQUIDS", UOP, Inc., Des Plaines, Illinois, Report No. FE--2645-02, May 1979.

Abstract: Feedstock for demex deashing of coal liquids was prepared by liquefying a slurry of Illinois No. 6 coal in a coal-derived solvent.

A-125 (Microfiche)

"COMPUTER-AIDED INDUSTRIAL PROCESS DESIGN: THE ASPEN PROJECT, Massachusetts Inst. of Tech., Cambridge, Report No. MIT--2295T9-11, December 15, 1978.

Abstract: The major efforts have been in program coding and testing. Parallel coding efforts have been in progress for functional models such as in the UOS, PPS, and costing systems.

A-126 (Microfiche)

Dunbar, D. N., B. G. Tunnah, "COMPUTER MODEL FOR REFINERY OPERATIONS WITH EMPHASIS ON JET FUEL PRODUCTION VOLUME III. DETAILED SYSTEMS AND PROGRAMMING DOCUMENTATION", Cordian Associates, Inc., New York, Report No. N--78-25235, June 27, 1978.

Abstract: The FORTRAN computing program predicts flow streams and material, energy, and economic balances of a typical petroleum refinery, with particular emphasis on production of aviation turbine fuels of varying end point and hydrogen content specifications. The program has a provision for shale oil and coal oil.

In addition to petroleum crudes, a case study feature permits dependent cases to be run for parametric or optimization studies by input of only the variables which are changed from the base case.

A-127 (Microfiche)

Johnson, J. E., "STORAGE AND TRANSPORTATION OF SYNTHETIC FUELS. A REPORT TO THE SYNTHETIC FUELS PANEL", Oak Ridge National Lab., Tennessee, Report No. ORNL-TM--4307, September 1972.

B-001-P, A-001-P

REFINING OF SYNTHETIC CRUDES, Advances in Chemistry Series 179, American Chemical Society, Washington, D.C., 1979.

Abstract: Based on a symposium sponsored by the Division of Petroleum Chemistry at the 174th Meeting of the American Chemical Society, Chicago, Illinois, August 29 - September 1, 1977. Papers presented discuss Characterization of Syncrudes, Analysis of Hetero compounds in coal liquids, hydroprocessing of shale oil, two-staged thermal and catalytic hydrocracking process for athabasca bitumen, catalytic cracking of ridge bitumen, upgrading of primary liquids by hydrotreatment, catalytic hydroprocessing of solvent refined coal, investigation of cobalt-molybdenum - alumina catalysts for hydronitrogenation of coal derived oils, catalytic effect of active metals upon hydrodenitrogenation of heavy coal liquids, chemicals from coal-derived synthetic crude oils.

B-002, A-002

Schweiger, Robert G., "BURNING TOMORROW'S FUELS", Power, February, 1979.

Abstract: Discussion of combustion characteristics of various synthetic fuels utilized in industrial boilers, gas turbines and process equipment. Includes low, medium and high BTU SNG, coal derived liquids, oil shale liquids and solvent refined coal.

B-003-P, A-003-P, D-004-P, F-008-P

Moses, C. A., Naegeli, D. W., "FUEL PROPERTY EFFECTS ON COMBUSTOR PERFORMANCE", Southwest Research Institute presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San-Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-178.

Abstract:

Two combustor rigs have been used to study the sensitivities of combustor operation to the physical and chemical properties of fuels. Nineteen fuels including syn-fuels were used to accentuate the properties of concern: composition, viscosity and boiling-point distribution. Flame radiation and smoke were best correlated by hydrogen content rather than hydrocarbon structure; the soot formation was due to gas-phase reactions. Lean-blowout conditions were about the same for all fuels except that gasoline could be burned leaner at idle conditions. Ignition limits were more sensitive to volatility than viscosity. Gaseous emissions and combustion efficiency were not significantly affected by fuel properties although some sensitivity to boiling point distribution was evident. In all performance areas the syncrude fuels correlated in the same ways as the petroleum-derived fuels except for the NO_x emissions from the nitrogen containing shale oil fuel.

B-004-P, A-004-P

Synthetic Fuel/Turbine Fuel

Gallagher, J.P., ARCO, Harvey, Illinois "SYNTHESIS AND ANALYSIS OF JET FUEL FROM SHALE OIL AND COAL SYNCRUDES" prepared for NASA/Lewis Research Center, Contract No. NAS 3-19747, November 1976.

Abstract: Thirty-two jet fuel samples of varying properties were produced from shale oil and coal syncrudes, and analyzed to assess their suitability for use. TOSCO II shale oil, H-Coal and COED syncrudes were used as starting materials.

B-005

Shale Oil

Schora, F. C., Tarmen, P. B., Feldkinches, H. L., JGT Chicago, Illinois "OIL SHALE - PRESENT TECHNOLOGY AND THE IGT/A.G.A. PROCESS" Papers presented at 8th Synthetic Pipeline Gas Symposium in Chicago, Illinois, October 1976, 48 pages.

Abstract: The Papers described briefly various processes under consideration or under development for the conversion of oil shale.

B-006

Shale Oil

Weichman, The Superior Oil Company, Houston, Texas. "MULTI-MINERAL OIL-SHALE COMMERCIALIZATION" presented to AIChE, 81st Meeting, Kansas City, Missouri, April 1976.

Abstract: General information about Oil Shale and its byproducts: the multi-mineral process: Nahcolite, Shale Oil, Alumina, Soda Ash

B-007

Shale Oil/Hydrotreating

IGT, Chicago, Illinois. "THE IGT OIL SHALE PROCESS FOR ABOVE GROUND AND IN SITU HYDRORTORTING. Information submitted by F. Schora for subcommittee on Energy Research, Development and Demonstration, hearing on conversion of oil shale to synthetic fuels. October 1975, 20 pages.

Abstract: Report of a "new" process developed by IGT for the American Bar Association. The process produces either gas or oil from oil shale with very high recovery of the kerogen as compared to conventional retorting processes.

B-008-P

Oil Shale/Properties

TRW Energy System Planning Division, McLean, Virginia "OIL SHALE DATA BOOK" prepared for DOE, Contract No. DE-AC01-78RA32012, June 1979, 31 pages.

Abstract: Tables of shale oil composition from different processes.

B-009-P

Oil Shale/TOSCO II

Whitcombe, J. A. Vawter, R. G., The Oil Shale Corporation, Los Angeles, California, "THE TOSCO-II OIL SHALE PROGRESS" Prepared for "American Institute of Chemical Engineers" 79th National Meeting, March 16-20, 1975; 24 pages.

Abstract: Process description with some tables and graphs.

B-010-P-M

Shale Oil/Paraho

Sullivan, Stangeland, Rudy, Green, Frumkin; Chevron Research Center, Richmond, California "REFINING AND UPGRADING OF SYNFUELS FROM COAL AND OIL SHALES BY ADVANCED CATALYTIC PROCESSES" First Interim Report, Processing of PARAHO SHALE OIL performed for DOE, Contract No. EF-76-C-01-2315, April 1978, 224 pages.

Abstract: Advanced commercial petroleum processing technology was employed in pilot plant facilities to produce transportation fuels. Three refining works were identified for process design and cost estimate:

- (1) Hydrotreating followed by hydrocracking.
- (2) Hydrotreating followed by catalytic cracking.
- (3) Coking followed by hydrotreating.

For an alternative raw shale oil was hydrotreated to produce synthetic crude suitable for processing in an existing refinery.

B-011

Shale Oil/In Situ

Cottingham Place, DOE Laramie Energy Research Center, Laramie, Wyoming. "PREREFINING TRUE IN SITU SHALE OIL".

Abstract: Crude shale oil from true in situ retorting of shale was hydrotreated to produce a liquid product from which 98 percent of the sulfur and nitrogen had been removed.

B-012-P

Tar Sand

Proceedings of the 13th Intersociety Energy Conversion Engineering Conference, Vol. I, August 22-25, 1978, San Diego.

1. "JET FUELS FROM SHALE OIL: A NEAR TERM TECHNOLOGY". Harvey, B. M., Rancey, J., Hildebrand, R. U.S. DOE - jet fuel production. Discussion of past and current programs on refining shale oil with related tables.
2. "COMPARISON OF SHALE OILS FROM DIFFERENT SOURCES PRODUCED BY CONTROLLED - STATE RETORT". Durall, J. J., Bartke, T. C., DOE Laramie Energy Research Center - comparison of 6 different shales retorted under same conditions and analyzed for chemical and physical properties.
3. "THERMAL HYDROCRACKING OF ATHABASCA BITUMEN: EFFECT OF RECYCLE GAS PURITY ON PRODUCT YIELDS AND QUALITIES" Kulbe, Shah, Pruden, Denis, Energy Research Laboratory, DOE, Ottawa, Canada - Thermal hydrocracking of bitumen. Comparison of results with previously published results.

Articles from periodicals concerning news in the field of shale oil.

- 1) STATE-OF-THE-ART, ABOVE GROUND SHALE PROCESSING from IGT in HC-Process, February 1977.
- 2) SHALE CLOSEST AMONG SYNFUELS from ERDA Ph. White in "The Oil and Gas Journal", February 17, 1977.
- 3) PRICE, AIR REGS STALL SHALE-OIL INDUSTRY about Paraho process, in "The Oil and Gas Journal" February 28, 1977.
- 4) SHALE OIL FINALLY ROCKING OF DEAD CENTER IN US? from H. M Wilson in "The Oil and Gas Journal", June 18, 1979

B-014**Shale Oil, Paraho**

Robinson, E. T., "REFINING OF PARAHO SHALE OIL INTO MILITARY SPECIFICATION FUELS", Results of Phase I, Pilot Plant Studies Final Report and Preliminary Results of Phase II and III. Refining of up to 100,000 BBLs of crude Paraho Shale Oil, preliminary results and analysis. Presented at the 108th AIIME Annual Meeting, New Orleans, February 1979; Program for the DOE, DOD and US Navy.

Abstract: Development and demonstration in refining pilot plants, a method for producing specification and stable military fuels from crude Paraho shale oil. Maximizing yields of JP-5 and DFM while minimizing yields of 650+ bottoms (residual fuels).

B-015 (Microfiche)

Gallagher, J. P. et al "SYNTHESIS AND ANALYSIS OF JET FUEL FROM SHALE OIL AND COAL SYNCRUDES", November 1976, Atlantic Richfield Co. Harvey, Illinois, NTIS N77-12230.

B-016 (Microfiche)

"TRACE ELEMENTS ASSOCIATED WITH OIL SHALE AND ITS PROCESSING", May 1977, TRW Environmental Engineering Division, Vienna, Virginia, NTIS PB-283 038.

B-017**Shale Oil/Upgrading**

TRW, Energy Systems Group, McLean, Virginia "OIL SHALE DATA BOOK", Performed for DOE, Contract No. DE-AC-01-78RA32012, June 1979 Part 4, Upgrading.

Abstract: Broad description of methods or processes for improving the physical and chemical properties of shale oil and gas. The methods used are commonly practiced in the petroleum refining industry during conversion of petroleum to finished products, but modified to accomodate the special characteristics of shale oil. Also included is the treatment of the byproducts of oil shale processing, such as reduction of solids contained in shale oil, waste water treatment, and retorted shale disposals.

B-018 (Microfiche)

"TRACE ELEMENTS IN OIL SHALE", Progress Report, June 1976 - May 1977, Colorado University, Boulder, NTIS C00-4017-1.

B-019 (Microfiche)

Fruchter, J. S., et al, Battelle Pacific Northwest Labs., Richland, WA., "HIGH PRECISION TRACE ELEMENT AND ORGANIC CONSTITUENT ANALYSIS OF OIL SHALE AND SOLVENT-REFINED COAL MATERIALS", March 1977, BNWL-SA-6001.

Abstract:

THE APPLICATION OF A NUMBER OF SENSITIVE AND PRECISE METHODS FOR THE DETERMINATION OF TRACE ELEMENTS, HEAVY ELEMENT SPECIES AND ORGANIC COMPOUNDS IN MATERIALS FROM AN OIL SHALE RESEARCH RETORT PROCESS AND FROM A SOLVENT-REFINED COAL PILOT PLANT OPERATION ARE DISCUSSED. THE METHODS WERE CHOSEN BOTH FOR THEIR SENSITIVITY, AND ALSO FOR THEIR RELATIVE FREEDOM FROM INTERFERENCE EFFECTS. COAL LIQUIDS CONTAIN MUCH HIGHER CONCENTRATIONS OF AROMATIC COMPOUNDS, INCLUDING POLYNUCLEAR AROMATIC HYDROCARBONS (PNA'S). A LARGER RELATIVE FRACTION OF THE PNA'S IN SHALE OIL ARE ALKYL SUBSTITUTED. COAL LIQUIDS ARE ALSO CONSIDERABLY HIGHER IN PHENOLS (28 PERCENT) THAN IS SHALE OIL (2 PERCENT). N-HETEROCYCLICS ARE PRESENT IN HIGHER CONCENTRATION (GREATER THAN 8 PERCENT) IN SHALE OIL DUE TO THE HIGH NITROGEN CONTENT OF THE RAW SHALE. HYDROAROMATICS ARE COMMON IN COAL LIQUIDS BUT NEGLIGIBLE IN SHALE OIL. INORGANIC ELEMENTS AND SPECIATION MEASUREMENTS INDICATE SIGNIFICANT AMOUNTS OF THE TOXIC HEAVY ELEMENTS HG, AS, ZN, AND SE IN EFFLUENT OIL WATER AND GAS STREAMS.

B-020

Berry, K. L., Rio Blanco Oil Shale Company, Denver, Colo., "COMBINED RETORTING TECHNIQUE FOR OIL SHALE", in CEP, September, 1979.

Abstract: The process ratio and the resource yield ratios both favor combined in situ and surface retorting. Studies indicate that this combination will also prove the economics.

B-021

Cottingham, P. L., Laramie Energy Res. Center, "PREREFINING TRUE IN SITU SHALE OIL", Print for 13th Intersociety Energy Conversion Engineering Conference, Reprint from Oct. 1978.

Abstract: Crude shale oil from true in situ retorting of shale near Rock Springs, Wyoming was hydrotreated at 1,500 psig pressure and 800°F to produce a liquid product from which 98 percent of the sulfur and nitrogen had been removed. The product was distilled to yield 36.7 volume percent of the fuel as gasoline containing 24 parts per million nitrogen and 51.0 percent as Nos. 1 through 4 diesel fuels qualified as low-sulfur, high-cetane diesel fuels. Hydrotreating the crude at 2,200 psig produced a total liquid product with only 53 ppm nitrogen and less than 100 ppm sulfur after 888 hours operation. This experiment continued through 1668 hours onstream; the final products are being analyzed.

B-022

Cottingham P. L., Nickerson, L. G., Laramie Energy Res. Center, "HYDROCRACKING OF IN SITU SHALE OIL", Presentation to the Symposium on Oil Shale, 172nd National Meeting of Am. Chem. Soc., Aug/Sept. 1976.

Abstract: A group of once-through laboratory hydrocracking experiments was made with crude in situ shale oil from underground combustion retorting of Green River oil shale. Nickel oxide-molybdenum oxide catalyst was used. Best sulfur and nitrogen removal were obtained at 800°F and 0.56 V_0/V_c /hr. A longer hydrocracking run was made at 800°F and 0.48 V_0/V_c /hr and the liquid product was distilled into gasoline-boiling-range naphtha and three successive higher-boiling diesel fuels.

B-023

Cottingham, P. L., C. M. Frost, Laramie Energy Res. Center, "METHODS FOR RE-FINING CRUDE SHALE OIL PRODUCED BY IN SITU RETORTING".

Abstract: Crude shale oil produced during in situ retorting by the Bureau of Mines at rock Springs, Wyo., was refined by three schemes. Yields of reformat and cat-cracked gasoline as volume-percents of the crude, and research-method octane numbers (with 3 ml TEL) for the three methods were as follows: First method, 32 pct reformat, 90 octane; 19.5 pct cracked gasoline, 99.2 octane. Second method, 29 pct reformat, 81.1 octane; 21.3 pct cracked gasoline, 99.6 octane. Third method, 28.2 pct reformat, 86 octane; 28.7 pct cracked gasoline, 95.9 octane.

B-024

Dr. Allan Sass, Occidental Oil Shale Inc., "STATUS OF THE OXY, MODIFIED IN-SITU OIL SHALE PROJECT", Presentation at Pacific Energy Ass. Meeting, October 1979.

Abstract: This paper outlines the magnitude of the potential for enhanced domestic oil production that is represented by oil shale. A description of the Oxy process is presented along with a summary of the results obtained during the testing of the process in large scale field experiments in Colorado. The current efforts to commercialize this technology on Federal Tract C-b, is also reviewed.

B-025

Poulson, R. E., et al, Laramie Energy Res. Center, "MINOR ELEMENTS IN OIL SHALE AND OIL SHALE PRODUCTS", Report of Investigations, (Co-authors Smith, Young, Robb, Spedding) 1976.

Abstract:

This paper is limited to elemental analyses without regard to particular chemical compounds. Order of magnitude minor elemental analyses for several Green River Formation oil shales, shale oils, and retort waters are presented. The oil-shale analyses show a remarkable uniformity between Colorado Piceance Creek Basin Mahogany Zone and Saline Zone oil shales. Comparison with earlier data of other workers extends this uniformity to rich and lean Mahogany zone oil shales, to the Mahogany and R-4 zones of the Piceance Creek (Colorado) and Uinta (Utah) Basins.

B-026

Jensen, H. B., R. E. Poulson, G. L. Cook, Laramie Energy Res. Center, "CHARACTERIZATION OF A SHALE OIL PRODUCED IN SITU RETORTING", ACS Division of Fuel Chemistry, Reprints, Vol. 15, No. 1, March/April 1971.

Abstract: This paper describes two crude shale oils that were recovered from successful in situ-combustion retorting experiments. The description is based primarily on the results of the application of the Bureau of Mines crude shale-oil analysis to these two crudes. In addition to describing the properties of the two in situ crudes in terms of this analysis, the properties of crude shale oils from aboveground retorts are also described. Comparison of the oils from the aboveground retorts with each other are made in order to determine the effect of change of retorting parameters upon oil character.

B-027

Cottingham, P. L., Laramie Energy Research Center, "DISTRIBUTION OF NITROGEN IN HYDROCRACKED IN SITU SHALE OIL", in Ind. Eng. Chem., Vol. 15, No. 3, 1976.

Abstract:

Crude shale oil from underground in situ retorting of Wyoming oil shale was hydrocracked over a nickel-molybdena catalyst in a single-pass operation. The liquid product was fractionally distilled into naphtha and heavier oil. The 54 fractions distilling above naphtha were collected at 5 °F intervals (at 10 mm absolute pressure), and nitrogen percentages were determined on these. The hydrocracking eliminated 98% of the nitrogen from the oil, but the boiling-range distribution of the nitrogen compounds remaining in the oil resembled that of the nitrogenous components in raw shale oil and in hydrocracked gas-combustion shale oil.

B-028

Cottingham, P. L. , Laramie Energy Res. Center, "DIESEL FUELS FROM SHALE OIL", no date (probably middle 70's).

Abstract: High-boiling shale oil produced from Rocky Mountain oil shale can be reduced in molecular weight by recycle thermal cracking and by coking. Diesel fuels of good quality have been made from the cracked shale oil by acid and caustic treating. Diesel oil made by this process performed acceptably in an in-service test for powering a railroad engine in a 750-hour test. Better quality diesel fuels were made by hydrogenation of a coker distillate. Even better quality diesel fuels, suitable also for use as high-quality distillate burner fuels, have been made by hydrocracking of a crude shale oil from underground in situ retorting experiments conducted by the Laramie Energy Research Center in Wyoming.

B-029

Lanning, W. C., Bartlesville Energy Res. Center, "THE REFINING OF SHALE OIL", Study for the DOE, May 1978.

Abstract:

The refining of shale oil is reviewed to assess the current state-of-the-art, especially as to the availability of technology suitable for operation on a commercial scale. Oil shale retorting processes as they affect the quality of the crude shale oil for refining, exploratory research on the character and refining of shale oil, and other published refining background leading to the present status are discussed. The initial refining of shale oil requires the removal of a large concentration of nitrogen, an added step not required for typical petroleum crude oils, and recently published estimates show that the total cost of refining will be high. Specific technology is reported by industry to be technically proven and available for commercial-scale refining. Although the refining will be more costly than that of petroleum, the viability of a shale oil industry will also be affected greatly by the technology and costs of producing the crude shale oil, environmental costs, and future price and tax treatment, and these are outside the scope of this study of refining.

B-030

Frumkin, H. A., E. J. Owens, R. B. Sutherland, Chevron Research Co., "ALTERNATIVE ROUTES FOR REFINING PARAHIO SHALE OIL", from CEP, Sept. 1979.

Abstract: The hydrotreating-FCC and hydrotreating-hydrocracking processing alternatives are most efficient for refining Paraho shale to produce distillate transportation fuels.

B-031

Schara, F. C., et al, Institute of Bas Technology, "HYDROCARBON FUELS FROM OIL SHALE", Presentation at 11th Intersociety Energy Conversion Engineering Conf., Sept 1976.

Abstract: A new process for producing substitute natural gas and/or middle-distillate-type oils from oil shale is described. This process employs controlled, countercurrent heating of the shale in the presence of hydrogen at moderate pressure levels. Controlled heating in hydrogen promotes almost complete recovery of the kerogen (organic carbon) compared with about 75% recovery by conventional retorting.

B-032

Fox, J. P., K. K. Mason, J. J. Duvall, "PARTITIONING OF MAJOR, MINOR, AND TRACE ELEMENTS DURING SIMULATED IN SITU OIL SHALE RETORTING IN A CONTROLLED-STATE RETORT", by Lawrence Berkeley Laboratory and Laramie Energy Tech. Center, (probably 1979)

Abstract: Analysis of shale oil for 49 elements during 15 runs.

B-033

Frost C. M., R. E. Poulson, Laramie Energy Res. Center, "NITROGEN TYPES IN SYNCRUDES FROM IN SITU CRUDE SHALE OIL", (Probably from middle '70ies)

Abstract: Analysis of hydrogenated shale oil, compared with multistep syncrude.

B-034

Laramie Energy Tech. Center, "SHALE OIL ANALYSIS", Data sheets received from Laramie E.T. Center on Feb. 25th, 1980.

Abstract: Reports of analysis of crude shale oil between 1965-1979, Paraho Retort Crude Shale Oil.

B-035

Frost, C. M., R. E. Poulson, H. B. Jensen, "PRODUCTION OF SYNTHETIC CRUDE FROM SHALE OIL PRODUCED BY IN SITU COMBUSTION RETORTING", Laramie Energy Research Center, probably from 1972 or 73.

Abstract: Yield datas, analysis of syncrude and comparison with natural petroleum.

B-036

Frost, C. M., Laramie Energy Res. Center, "REFINING OF CRUDE SHALE OIL PRODUCED BY IN SITU RETORTING", Symposium on Quality of Synthetic Fuels, ACS- Meeting, April 1972.

Abstract: Properties of in-situ crude shale oil and its distillate fractions, hydrodenitrogenation and reforming of naphtha and catalytic cracking of 400°F+ hydrogenate.

B-037

Frost, C. M., H. B. Jensen, Laramie Energy Res. Center, "HYDRODENITRIFICATION OF CRUDE SHALE OIL", Presented at ACS - Meeting, April 1973.

Abstract: Study to determine the effects of processing variables on the rates at which various types of nitrogen compounds are removed from crude shale oil.

B-038

Nutter, J. F., C. S. Waitman, OTSCO Corp., "OIL SHALE ECONOMICS UPDATE", Prepared for AIChE, 14th Annual Techn, Meeting, April 1978.

Abstract: TOSCO Process with yield datas, including upgrading of shale oil crude. Economics of Colony Shale Oil Project in 1976 dollars.

B-039

McNamara, P. H., J. P. Humphrey, "HYDROCARBONS FROM EASTERN OIL SHALE" a Dow Chemical Report in CEP, September 1979.

Abstract: A look at the four-year study Dow has undertaken to determine the feasibility of recovering low-Btu gas from Michigan Antrim shale.

B-040

Dougan, P. M., "THE BX IN SITU OIL SHALE PROJECT" an Equity Oil Company Report in CEP, September 1979.

Abstract: If this effort succeeds, the way will be open to develop a major portion of the world's largest single oil shale deposit.

B-041

Griswold, C. F. et. al, "LIGHT OLEFINS FROM HYDROGENATED SHALE OIL" (co-authors Ballut, Kavarianian, Dickson, Yesavage) Colorado School of Mines, Golden Colorado, Artical published in CEP, September 1979.

Abstract: Steam pyrolysis of hydrogenated shale oil gives yields of major gaseous components that compare well with those from petroleum fractions, and even higher yields of ethylene.

B-042-P

Shendrikar, A. D., G. B. Faudel, "DISTRIBUTION OF TRACE METALS DURING OIL SHALE RETORTING" TOSCO Corporation, Golden Colorado, in Environmental Science & Technology, March 1978.

Abstract: Three samples of raw oil shale from the Green River formation of Western Colorado were retorted under conditions simulating a potentially commercial process.

B-043 (Microfiche)

Sullivan, R. F., B. E. Stangeland, "CATALYTIC HYDROPROCESSING OF SHALE OIL TO PRODUCE DISTILLATE FUELS", Chevron Research Co., Richmond, California, Sec. Report No. CONF-770814--P2; CONE-80305--P2, February 1978.

Abstract: Results are presented of a study to demonstrate the feasibility of converting whole shale oil to synthetic crude resembling a typical petroleum distillate. Paraho shale oil was used in the study. Results show that Paraho shale oil can readily be dewatered and deashed by heating and settling. It can then be hydrodenitrified to make a premium refinery feedstock resembling desulfurized petroleum distillates.

B-44 (Microfiche)

Chappell, W. R. "TRACE ELEMENTS IN OIL SHALE", Colorado University, Boulder, Colorado, Report No. COO--4017-3, 1979.

Abstract: The overall objective of the program is to evaluate the environmental and health consequences of the release of toxic trace elements (AS, R, F, MO, SE) by shale oil production and use.

B-045 (Microfiche)

Curtin, D. J., J. D. Dearth, G. L. Everett, M. P. Grosboli, G. A. Myers, "ARSENIC AND NITROGEN REMOVAL DURING SHALE OIL UPGRADING", Atlantic Richfield Company, Dallas, Texas, Sec. Rept. No. CONF-780902--92, 1978.

Abstract:

A reactor model for removal of AS and N from shale oil is presented.

B-046

Fox, J. R., K. K. Mason, J. J. Duvall, "PARTITIONING OF MAJOR, MINOR, AND TRACE ELEMENTS DURING SIMULATED IN SITU OIL SHALE RETORTING IN A CONTROLLED-STATE RETORT", California University, Berkely, April 1979.

Abstract: The partitioning of 49 elements during 15 runs of the Larmie Energy Technology Center's controlled-state retort was investigated.

B-047

Lanning, W. C., "REFINING OF SHALE OIL", Department of Energy, Bartlesville, Oklahoma, Bartlesville Energy Research Center, Report No. BERC/IC--77/3, May 1978.

Abstract: The refining of shale oil is reviewed to assess the current state-of-the-art, especially as to the availability of technology suitable for operation on a commercial scale. Oil shale retorting processes as they affect the quality of the crude shale oil for refining, exploratory research on the character and refining of shale oil. And other published refining background leading to the present status are discussed.

C-001

R. M. Parsons Company, "PETROLEUM ANALYSIS, OCD REFINERY FOR DOW CHEMICAL", Job No. 5350-1.

Abstract: Complete Analysis of Petroleum Crude and its Fractions.

D-001

"GAS TURBINE LIQUID FUEL SPECIFICATIONS", General Electric, GEI-41047G.

Abstract: Itemization of fuel specifications for several types of liquid fuels suitable for use in General Electric heavy duty gas turbines.

D-002

"STANDARD SPECIFICATION FOR GAS TURBINE FUEL OILS", ANSI/ASTM D 2880-78.

Abstract: Itemization of ASTM fuel specifications for gas turbine engines.

D-003, F-006

Clayton, R. M., "A PARTIAL OXIDATION STAGING CONCEPT FOR GAS TURBINES USING BROADENED SPECIFICATION FUELS", Jet Propulsion Laboratory, California Institute of Technology, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-169.

Abstract: A concept is described for using a very fuel-rich partial oxidation process as the first stage of a two-stage combustion system for onboard processing of broadened specification fuels to improve their combustion characteristics. Results of an initial step in the experimental verification of the concept are presented, where the basic benefits of H_2 enrichment are shown to provide extended lean-combustion limits and permit simultaneous achievement of ultralow levels of NO_x , CO and HC emissions. The H_2 required to obtain these results is within the range available from a partial oxidation precombustion stage. Operation of a catalytic partial oxidation reactor using a conventional aviation turbine fuel (JP5) and an unconventional fuel (blend of JP5/xylene) is shown to produce a "fuel gas" stream with near-theoretical equilibrium H_2 content. However, a number of design considerations indicate that the precombustion stage should be incorporated as a thermal reaction.

D-004-P, A-003-P, B-003-P F-008-P

Moses, C. A., Naegeli, D. W., "FUEL PROPERTY EFFECTS ON COMBUSTOR PERFORMANCE", Southwest Research Institute presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San-Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-178.

Abstract:

Two combustor rigs have been used to study the sensitivities of combustor operation to the physical and chemical properties of fuels. Nineteen fuels including syn-fuels were used to accentuate the properties of concern: composition, viscosity and boiling-point distribution. Flame radiation and smoke were best correlated by hydrogen content rather than hydrocarbon structure; the soot formation was due to gas-phase reactions. Lean-blowout conditions were about the same for all fuels

except that gasoline could be burned leaner at idle conditions. Ignition limits were more sensitive to volatility than viscosity. Gaseous emissions and combustion efficiency were not significantly affected by fuel properties although some sensitivity to boiling point distribution was evident. In all performance areas the syncrude fuels correlated in the same ways as the petroleum-derived fuels except for the NO_x emissions from the nitrogen containing shale oil fuel.

D-005, E-002, F-013

Foster, Allen D., Doering, Harvey von E., Hicky, Joseph W., "FUEL FLEXIBILITY IN HEAVY DUTY GAS TURBINES", Gas Turbine Products Division, General Electric Company, 1976, GER-2222k.

Abstract: Detailed presentation of gas turbine capabilities to handle a variety of fuels including low Btu gases, distillate fuels and heavy liquid fuels. Discussed fuel specifications, pretreatment processes and capabilities, and associated turbine maintenance problems.

D-006

"GAS TURBINE LIQUID FUEL SPECIFICATIONS", General Electric Company, GEI-41047G.

Abstract: Presents fuel chemical and physical specifications for a variety of fuels suitable for use in General Electric gas turbines.

D-007

"SPECIFICATIONS FOR GAS TURBINE FUEL GASES", General Electric Company, GEI0-41040C.

Abstract: Specifications for gaseous fuels to be utilized in General Electric gas turbines are presented.

D-008

Gas Turbine/Fuel Specifications

General Electric. "GAS TURBINE LIQUID FUEL SPECIFICATIONS" No. FEJ-41407G.

Abstract: Content: Fuel Classification and Operational Consideration.
Fuel Specification.
Fuel Handling and Treatment.
Non-Fuel Contaminants.
Fuel and Additive Evaluation and Sampling.
Fuel Descriptions.
Meaning of Specification Tests.
Fuel Analysis Data Requirements.

D-009

BBC - Brown Boveri Turbomachinery, Inc., "FUEL SPECIFICATION - BBT: FS - RO", Undated Spec. from BBC.

Abstract: Detailed specification for gaseous and liquid turbine fuels with appendix 'Guidelines for the handling and storage of gas turbine liquid fuels'.

D-010

Fear, J. S., Lewis Research Center, NASA BROAD-SPECIFICATION FUELS COMBUSTION TECHNOLOGY PROGRAM--STATUS AND DESCRIPTION", presentation at the Gas Turbine Conf., New Orleans, LA., March 10-13, 1980.

Abstract: The use of "broad-specification" fuels in aircraft gas turbine engines can be a significant factor in offsetting anticipated shortages of current-specification jet fuel in the latter part of the century. The changes in fuel properties accompanying the use of broad-specification fuels will tend to cause numerous emissions, performance, and durability problems in currently-designed combustion systems. The NASA Broad-Specification Fuels Combustion Technology Program is a contracted effort to evolve and demonstrate the technology required to utilize broad-specification fuels in current and next generation commercial Conventional Takeoff and Landing (CTOL) aircraft engines, and to verify this technology in full-scale engine tests in 1983. The program consists of three phases: Combustor Concept Screening, Combustor Optimization Testing, and Engine Verification Testing.

D-011

Gleason, C. C. and J. A. Martone, General Electric and U. S. Air Force, "FUEL CHARACTER EFFECTS ON J79 AND F101 ENGINE COMBUSTOR EMISSIONS", presentation at the Gas Turbine Conf., New Orleans, LA., March 10-13, 1980.

Abstract: Results of a program to determine the effects of fuel properties on the pollutant emissions of two US Air Force aircraft gas turbine engines are presented. Thirteen test fuels, including baseline JP-4 and JP-8, were evaluated in a cannular (J79) and a full annular (F101) combustor. The principal fuel variables were hydrogen content, aromatic structure, volatility, and distillation end point. Data analysis shows that fuel hydrogen content is a key fuel property, particularly with respect to high power emissions (oxides of nitrogen and smoke), and that low power emissions (carbon monoxide and hydrocarbons) are more dependent on fuel atomization and evaporation characteristics.

D-012

Gleason, C. C. and D. W. Bahr, General Electric Aircraft Engine Group, "FUEL PROPERTY EFFECTS ON LIFE CHARACTERISTICS OF AIRCRAFT TURBINE ENGINE COMBUSTORS", presentation at the Gas Turbine Conf., New Orleans, LA., March 10-13, 1980.

Abstract: Results of a program to determine the effects of fuel properties on the life characteristics of two USAF/General Electric aircraft turbine engine combustors are presented. Thirteen test fuels were evaluated in an older technology cannular combustion system (J79) and in an advanced technology, virtually smokeless, compact, annular combustion system (F101) over wide ranges of simulated engine operating conditions.

D-013

Midkiff, L. A., "SO₂-REMOVAL: WHERE DO WE STAND?", from Power, Nov. 1978.

Abstract: The past five years have seen wet-scrubbing systems come of age, while witnessing the birth of dry-scrubbing alternatives. Armed with this new experience, how are we fixed to meet future requirements of reliability, efficiency, and cost under stringent emissions standards?

D-014 (Microfiche)

Roessler, W. U., et al, "INVESTIGATION OF SURFACE COMBUSTION CONCEPTS FOR NO CONTROL IN UTILITY BOILERS AND STATIONARY GAS TURBINES", Aerospace Corp., El Segundo, CA., August 1973, NTIS: PB-224 424.

Abstract: The report reviews the state of the art of concepts of surface combustion (that occurring near a solid surface) and assesses their applicability to large utility boilers and stationary gas turbines. Catalytic combustion looks promising for gas turbines.

D-015 (Microfiche)

Downs, W., "EQUIMOLAR NO-NO₂ ABSORPTION INTO MAGNESIA SLURRY: A PILOT FEASIBILITY STUDY", Babcock and Wilcox Co., Nov. 1971, NTIS: PB-223 579.

Abstract: Investigation of the feasibility of absorption of equimolar concentrations of NO_x into MgO slurry on a 1500 cfm wet scrubbing pilot plant. A wet scrubbing pilot plant consisting of several scrubbers was modified by the inclusion of an additional scrubber to enable series scrubbing of fly ash, sulfur dioxide, and finally nitrogen oxides. Gaseous nitrogen dioxide was injected into the flue gas following the SO₂ scrubber but before the NO_x scrubber. Seventeen tests were performed to evaluate parameters including the liquid-to-gas ratio, the ratio of NO₂ to NO, slurry concentration, stoichiometry, and gas flow rate. NO_x absorption was very poor for all conditions tested.

D-016

Junpei, Ando, et al, Processes Research, Inc., Cincinnati, Ohio, "NITROGEN OXIDE ABATEMENT TECHNOLOGY IN JAPAN, 1975", NTIS: PB-276 948.

Abstract: The report documents development, demonstration, and control now in progress in Japan on Japanese processes pertaining to NOx abatement from flue gases. It briefly includes Japanese environmental emission and control standards, and measurement methods. It presents control process descriptions, states of development, advantages, disadvantages, economics, and flow sheets for 13 processes (including combustion control, reduction, and absorption) for NOx abatement from waste gases. A new type of burner seems most promising for NOx removal from flue gases.

D-017

"DEMETALLIZATION CATALYST TESTS ON HEAVY RESIDUAL OILS" by Marshillin, V. V., Y. K. Vail, B. A. Lipkind, A. V. Agafoner, All Union Scientific Res. Inst. of Oil Refining, Moscow USSR and Maruhn P., G. Nongbri, Hydrocarbon Research Inc. Lawrenceville, New Jersey and Roheds, W. F., U.S. EPA, prepared for EPA; June 1978.

Abstract: In this report, all tests using USA catalyst have been described by the United States and all tests using USSR catalyst have been described by the USSR, and each country describes its equipment and operating procedures used in carrying out the tests. Included for each aging test are graphs showing degree of demetallization and desulfurization and the rate of catalyst deactivation. Fresh and used catalyst analyses are presented along with detailed run summaries and product inspections.

D-018

Eisen, F. S., "PREPARATION OF GAS TURBINE ENGINE FUEL FROM SYNTHETIC CRUDE OIL DERIVED FROM COAL. FINAL REPORT ON PHASE 2, Sun Oil Company, Marcus Hoos, PA, Report No. Ad-A-007923, February 1975.

Abstract: A 232 gallon gas turbine fuel sample containing 23 volume percent aromatics (20-25 volume percent specification target). Was prepared from synthetic crude oil (syncrude) derived from Western Kentucky coal. The seven fuel specifications designated as most important were all met with the exception of smoke point.

D-019

Klarman, A. F., A. J. Rollo, "EFFECT OF FUEL BOUND NITROGEN ON OXIDES OF NITROGEN EMISSION FROM A GAS TURBINE ENGINE", Naval Air Propulsion Test Center, Trenton, New Jersey, Report Number Ad-A--048382

Abstract: Fuels of varying nitrogen content were tested in a T63-A-5A engine to measure their effects on exhaust gas emissions.

D-020

Wolk, R. H., S. A. Vejtasa, "ELECTIRC UTILITY FOSSIL FUELS BEYOND 1985", Electric Power Research Inst., Palo Alto, CA, Conf. 780902-P4, Sept. 1978.

Abstract: Potential markets have been identified for liquid boiler, turbine, and combined cycle fuels, solid fuel (SPC), methanol.

D-021

Fejer, a. A., "DEVELOPMENT OF GAS TURBINE FUELS AND COMBUSTION. AN OVERVIEW", Institute of Gas Technology, Chicago, Illinois, 1979, Report CONF-790337--4.

Abstract: Describes the characteristic features of the gas turbine engines, contrasting them with their chief competitor, the steam cycle. The focus is on the aerodynamic processes in the combustion chambers of traditional engines and includes an outline of the changes that are to be expected with the introduction of the synthetic and coal derived fuels.

E-001

Prem, L. L., Williams, W. R., "ELECTROCOALESCER COMPARISON PERFORMANCE TESTS", Atomics International Division of Rockwell International, U.S. Army Mobility Equipment Research and Development Command, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers.

Abstract: Validation tests were carried out based upon tests specified in Military Specification MIL-F-8901. The Electrocoalescer has demonstrated excellent performance, has passed the validation test, and showed an improved performance over that of the Military Standard Filter Separator. When tested with diesel fuel, the improvement was on the order of a factor of 10 or more. Moreover, it demonstrated a lower overall pressure drop. Use of the Electrocoalescer in fuels decontamination service is expected to result in cleaner fuels and longer filter life.

E-002, D-005, F-013

Foster, Allen D., Doering, Harvey von E., Hickey, Joseph W., "FUEL FLEXIBILITY IN HEAVY DUTY GAS TURBINES", Gas Turbine Products Division, General Electric Company, 1976, GER-2222k.

Abstract: Detailed presentation of gas turbine capabilities to handle a variety of fuels including low Btu gases, distillate fuels and heavy liquid fuels. Discussed fuel specifications, pretreatment processes and capabilities, and associated turbine maintenance problems.

E-003

Krulls, G. E., "GAS TURBINE LIQUID FUEL TREATMENT AND ANALYSIS", Journal of Engineering for Power, General Electric Company, January 1975.

Abstract: A discussion of the gas turbine and its liquid fuel burning experience leads into present concepts and practices. A description is given of the fuel treatment equipment including fuel washing, vanadium inhibition, fuel analysis and system automation. Fuel washing by centrifugal means as well as electrostatic techniques are presented. The effect of fuel parameters on system size, cost and performance is evaluated. A summary of the experience gained shows that fuel treatment has indeed become a practical procedure.

E-004

Pitrolo, A. A., Bioko, A., Dreyman, S. S., Hickey, J. W., "HEAVY FUEL TREATMENT SYSTEMS," General Electric Company, 1974.

Abstract: The paper examines the capability and associated pretreatment and combustion problems of General Electric gas turbines firing heavy residual and crude oils. Pretreatment system capabilities and equipment are discussed in addition to turbine and compressor cleaning and maintenance practices.

E-005

Byam, J. W., Jr., Dreyman, S. S., Pitrolo, A. A., "RESIDUAL FUEL TREATING AND HANDLING FOR BASE LOAD GAS TURBINES", General Electric Company, presented at the Gas Turbine Conference and Products Show, Houston, Texas, March 2-6, 1975. American Society of Mechanical Engineers Publication 75-GT-22.

Abstract: This paper reviews the operating and maintenance experience of heavy fuel fired gas turbines used for base load power generation in an industrial complex. The data presented are based on over a quarter of a million fired hours of heavy fuel burning experience for ten gas turbines located in the Rhone Progil chlorine plant of Pont-de-Claix, France. A brief description of the turbine being studied and the arrangement of the power generation equipment in the chlorine plant is given. Three prime factors affecting maintenance/operation of the plant are discussed: physical and chemical properties of the fuel; environmental conditions of the site; and mode of operation for the power generation equipment. A description of the type of maintenance inspections performed in the gas turbine is given in detail. The logged maintenance data for the plant is discussed as well as the maintenance performed on both the turbine and the turbine auxiliary components. Specific data are presented showing the causes of the forced outages and the year by year availability from the time of commissioning through 1973.

E-006

Foster, A. D., "RESIDUAL FUEL TREATMENT", General Electric Company, presented at the General Electric Gas Turbine State of the Art Seminar, September 13-17, 1970. Saratoga Springs, New York, SOA-29-70.

Abstract: The paper discusses pretreatment system and equipment for removal of trace alkali earth metals from heavy oils such as #6, residual and crude.

E-007

Krulls, G. E., "A SYSTEMS APPROACH TO LIQUID FUEL TREATMENT, Encotech Incorporated, presented at the Gas Turbine Conference and Products Show, Houston, Texas, March 2-6, 1975, American Society of Mechanical Engineers Publication 75-GT-84.

Abstract: Liquid fuel treatment systems are available in a variety of types and sizes for various kinds of fuels. It is the purpose of this paper to make sense out of this maze of equipment and develop a systematic approach to component selection. In addition, the equations for calculating washing system efficiencies are presented as well as some new ideas in control systems and fuel analysis techniques. A gas turbine user should look at the total fuel history from refinery to exhaust stack as a part of the systems engineering work performed in the planning stages of a gas turbine or combined cycle installation.

E-008

Prok, G. M., G. T. Seng, "INITIAL CHARACTERIZATION OF AN EXPERIMENTAL REFUEL BROADENED - SPECIFICATION (ERBS AVIATION TURBINE FUEL", NASA Technical Memorandum 81440, January 1980.

Abstract: Characterization data and a hydrocarbon compositional analysis are presented for a research test fuel designated as an Experimental Referee Broadened-Specification (ERBS) aviation turbine fuel. This research fuel, which is a special blend of kerosine and hydrotreated catalytic gas oil, is a hypothetical representation of a future fuel should it become necessary to broaden current kerojet specifications. It will be used as a reference fuel in research investigations into the effects of fuel property variations on the performance and durability of jet aircraft components, including combustors and fuel systems.

E-009

Hannah, S. A., M. Jelus, J. M. Cohen, "REMOVAL OF UNCOMMON TRACE METALS BY PHYSICAL AND CHEMICAL TREATMENT PROCESSES", in Journal WPCF, by EPA, Cincinnati, Ohio. November 1977.

Abstract: To obtain data on the capability of physical-chemical treatment processes to remove trace metals from domestic wastewater, a comprehensive research project has been carried at the EPA Environmental Research Center in Cincinnati, Ohio, using continuous flow pilot plants.

E-010

Lanning, W. C., "DENITROGENATION OF COAL LIQUIDS", Department of Energy, Bartlesville, OK, Bartlesville Energy Technology Center, Report Number BETC/IC--78/1, July 1978.

Abstract: The published literature related to denitrogenation of synthetic crude oils, primarily coal liquids, has been reviewed. The principal background comes from the area of petroleum refining and, more specifically, from the development of processes to upgrade residuum by hydrogenation and to hydrocrack heavier fractions to lighter distillable products.

F-001

Pierce, R. M., Smith, C. E., Hinton, B. S. "ADVANCED COMBUSTION SYSTEM FOR STATIONARY GASTURBINE ENGINES", Volumes I through IV, Pratt & Whitney Aircraft Group, Government Products Division, United Technologies Corporation, Prepared for U.S. Environmental Protection Agency, Office of Research and Development, (Final Draft Report, not officially released).

Abstract: Alternative turbine combustion techniques studied for the purpose of minimizing NO_x emissions. Fuels studied include residual oil and synthetic oils. Best combustion system is two-staged firing (i.e. rich burn-quick quench).

F-002

Javetski, John, "THE CHANGING WORLD OF GAS TURBINES", Power. September 1978.

Abstract: Provides a general overview of gas turbine design, technology improvements and anticipated changes in future turbines primarily as a result of energy efficiency and environmental demands.

F-003

"KLEENAIRE DENOX SYSTEMS FOR REMOVAL OF OXIDES OF NITROGEN, CARBON MONOXIDE, AND CARBON PARTICULATES FROM INTERNAL COMBUSTION ENGINES, STEAMERS, BOILERS, TURBINES, PETROCHEM HEATERS, ETC.", Nevgas Nitrogen Corporation.

Abstract: Manufacturer's sales brochure for nitrogen oxide removal from combustion gases.

F-004

Pillsburg, P. W., Singh, P. O., John P., Stein T. R., Mulik, P. R. "FUEL EFFECTS IN RECENT COMBUSTION TURBINE BURNER TESTS OF SIX COAL LIQUIDS", presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-137.

Abstract: Comparative tests have been made in combustion turbine burners between six coal derived liquid (CDL) fuels and No. 2 distillate oil. All CDL fuels were evaluated in a half-scale (by diameter) combustor test rig, while one CDL fuel was also evaluated in a full scale high pressure combustion rig. The effects of these fuels on emissions of smoke and oxides of nitrogen, and on combustor metal temperature are discussed. Also observed in the testing were flame radiation, post-test combustor cleanliness, and emissions of carbon monoxide and hydrocarbons. Two of the CDLs do appear to be within the tolerance band which present combustion turbines can accept with the exception of elevated NO_x emissions. This work is part of an Electric Power Research Institute program to develop burners for coal derived liquids.

F-005

Sims, C. T., Doering, H. van E., Smith, D. P., "EFFECTS OF THE COMBUSTION PRODUCTS OF COAL-DERIVED FUELS ON GAS TURBINE HOT-STAGE HARDWARE", General Electric Company, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-160.

Abstract: This paper reports a DOE-sponsored program to evaluate the effect of the combustion products of coal-derived fuels on current and potential materials used in gas turbine hot-section components and on the plugging of cooling holes in air-cooled airfoils. Atmospheric-pressure small burner rigs and a combustor operating at elevated pressures and design air flows, equipped with a segment of a first-stage nozzle (turbine simulator), were used in these evaluations.

F-006, D-003

Clayton, R. M., "A PARTIAL OXIDATION STAGING CONCEPT FOR GAS TURBINES USING BROADENED SPECIFICATION FUELS", Jet Propulsion Laboratory, California Institute of Technology, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-169.

Abstract: A concept is described for using a very fuel-rich partial oxidation process as the first stage of a two-stage combustion system for onboard processing of broadened specification fuels to improve their combustion characteristics. Results of an initial step in the experimental verification of the concept are presented, where the basic benefits of H_2 enrichment are shown to provide extended lean-combustion limits and permit simultaneous achievement of ultralow levels of NO_x , CO and HC emissions. The H_2 required to obtain these results is within the range available from a partial oxidation precombustion stage. Operation of a catalytic partial oxidation reactor using a conventional aviation turbine fuel (JP5) and an unconventional fuel (blend of JP5/xylene) is shown to produce a "fuel gas" stream with near-theoretical equilibrium H_2 content. However, a number of design considerations indicate that the precombustion stage should be incorporated as a thermal reaction.

F-007

Battista, R. A., Farrell, R. A., "DEVELOPMENT OF AN INDUSTRIAL GAS TURBINE COMBUSTOR BURNING A VARIETY OF COAL-DERIVED LOW BTU FUELS AND DISTILLATE", Gas Turbine Division, General Electric Company, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-172.

Abstract: An industrial gas turbine combustor has been developed which is capable of operating over the gas turbine load range on a variety of coal-derived low Btu gases as well as No. 2 distillate fuel. At gas turbine cycle conditions using simulated coal-derived low Btu gas, CO emissions and combustor blowout characteristics are comparable to those obtained with current product line combustors burning No. 2 distillate. The results of laboratory single burner combustion tests with simulated low Btu gases ranges in heating value from 809 to 1369 kcal/NM³ (91-

154 Btu/scf) are described. Parametric studies were also conducted in which the moisture content of the fuel (at constant volumetric lower heating value) and heating value were varied. The results of these tests are compared with those obtained with a conventional constant cross-sectional area combustor and those of other investigators.

F-008

Mogal, J. C. Wolf, J. C., Bunker, W. W., "A HIGH TEMPERATURE TURBINE FOR OPERATION ON COAL-DERIVED FUEL" Curtiss-Wright Corporation, U.S. Department of Energy, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-173.

Abstract: An opportunity exists for generating clean high efficiency electric power from coal by integrating a low Btu coal gasification system with a combined gas turbine-steam turbine cycle. Achieving this objective is dependent on developing a gas turbine which can operate at temperatures over 2500°F (1427°C) in a combusted coal-gas environment. Transpiration-air-cooling of hot section blades and vanes is a concept which can effectively deal with both high gas temperatures and the aggressive atmosphere. A description of the concept early test experience and the building block testing approach for evaluating transpiration-air-cooling on simulated coal derived fuel are discussed.

F-008-P, D-004-P, A-003-P, B-003-P

Moses, C. A., Naegeli, D. W., "FUEL PROPERTY EFFECTS ON COMBUSTOR PERFORMANCE", Southwest Research Institute presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San-Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-178.

Abstract:

Two combustor rigs have been used to study the sensitivities of combustor operation to the physical and chemical properties of fuels. Nineteen fuels including syn-fuels were used to accentuate the properties of concern: composition, viscosity and boiling-point distribution. Flame radiation and smoke were best correlated by hydrogen content rather than hydrocarbon structure; the soot formation was due to gas-phase reactions. Lean-blowout conditions were about the same for all fuels except that gasoline could be burned leaner at idle conditions. Ignition limits were more sensitive to volatility than viscosity. Gaseous emissions and combustion efficiency were not significantly affected by fuel properties although some sensitivity to boiling point distribution was evident. In all performance areas the syncrude fuels correlated in the same ways as the petroleum-derived fuels except for the NO_x emissions from the nitrogen containing shale oil fuel.

F-009

Folsom, B. A., Courtney, C. W., Heap, M. P., "THE EFFECTS OF LBG COMPOSITION AND COMBUSTOR CHARACTERISTICS ON FUEL NO_x FORMATION", Energy and Environmental Research Corporation, presented at the Gas Turbine Conference and Exhibit and Solar

Energy Conference, San Diego, California, March 12-15, 1979. American Society of Mechanical Engineers Publication 79-Gt-185.

Abstract: The low Btu gas (LBG) combined gas and steam turbine power cycle is a potentially attractive alternative to the direct coal-fired steam cycle because of the potential for low sulfur emissions and high overall cycle efficiency. However, LBG may contain ammonia (NH_3) which could be converted to nitrogen oxides (NO_x) under typical combustion conditions. This paper examines the effects of LBG composition and combustor design on NO_x emissions. Low Btu gases of varying compositions were synthesized from bottled gases and fired in three atmospheric pressure flame reactors: diffusion flame reactor, flat flame reactor, and catalytic reactor. Nitrogen oxide emissions were found to be most sensitive to the concentrations of NH_3 and hydrocarbon fuel gas in the synthetic LBG. Lowest NO_x emissions were produced by the diffusion flame reactor operating at near stoichiometric conditions and the catalytic reactor operating fuel rich.

F-010

Keairns, D. L., Hamm, J. R., Ciliberti, D. F., Wolfe R. W., Ranadive, A. Y., Sverdrup, E. F., "DESIGN OF PRESSURIZED FLUID-BED COMBUSTOR/PARTICULATE CONTROL SYSTEM FOR RELIABLE TURBINE OPERATION", Westinghouse Research and Development Center, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-Gt-190.

Abstract: The commercial operation of coal-fired pressurized fluid-bed combustion-gas turbine plants for central station electric power generation or for industrial cogeneration applications depends on the reliable operation of the gas turbine. Reliable operation of the turbine is related to the particulate and chemical composition of the gases that it expands. This study is limited to an evaluation of particulates as they limit turbine life by erosion. Pressurized fluid-bed combustor design and operation trade-offs exist that affect the particle concentration and size ranges presented to the gas cleaning equipment. Gas cleaning equipment choices will subsequently effect the particulates going up to the turbine. The development of a particle profile model permits an assessment of the effect of these decisions on the particles that enter the turbine. Turbine tolerance models previously developed by Westinghouse are then used to estimate turbine life and the incremental energy cost penalty. The scope of the evaluation procedure is presented and selected parametric cases presented to illustrate available trade-offs for design, operation and cost.

F-011

Stringer, J., Enrilich, S., Slaughter, W. W., Dolbec, A. C., "ASSESSMENT OF HOT GAS CLEAN-UP SYSTEMS AND TURBINE EROSION/CORROSION PROBLEMS IN PFBC COMBINED CYCLE SYSTEMS", Fossil Fuel and Advanced Systems Division, Electric Power Research Institute, presented at the Gas Turbine conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-195.

Abstract: Alternative methods of producing electricity from coal while maintaining acceptable environmental standards are currently being examined in detail. One

such method involves the fluidized bed combustion of coal at elevated pressure using an acceptor in the fluidized bed to remove the sulfur. Steam is raised using heat exchangers within and above the bed, and the hot combustion gases are expanded through a gas turbine. A serious limitation in this system is the ability to reduce the particulate loading in the combustion gases to a level at which a gas turbine having acceptable life can be constructed. The turbine may be either a new design or a modification of a currently available engine and palliatives include lowering the turbine inlet temperature, lowering the gas velocity through the turbine and "hardening" the turbine by the selection of appropriate materials or claddings for the vanes and blades.

F-012

Boothe, W. A., McMuellen, J. C., "HEAVY DUTY GAS TURBINE DESIGN CHANGES FOR USE WITH LOW BTU COAL GAS", Gas Turbine Division, General Electric Company, presented at the Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, California, March 12-15, 1979, American Society of Mechanical Engineers Publication 79-GT-198.

Abstract: An MS5000 gas turbine is now being redesigned for integrated operation on low Btu Lurgi coal gas in the Powerton Gasification Combined Cycle Test Facility. Air is extracted from the machine to provide process air for the gasifiers and a heat recovery steam generator provides steam for the gas plant. This paper describes the design modifications to the gas turbine and its control system to accommodate such operation. Since the facility will demonstrate operation in a variety of control modes using gas produced from a wide range of domestic coals, the gas turbine control system emphasizes flexibility and incorporates several functions unique to low Btu gas applications. Major modifications to the fuel and combustion systems are also required. Test results on the resulting new combustor design are reported in a companion paper.

F-013, D-005, E-002

Foster, Allen D., Doering, Harvey von E., Hickey, Joseph W., "FUEL FLEXIBILITY IN HEAVY DUTY GAS TURBINES", Gas Turbine Products Division, General Electric Company, 1976, GER-2222k.

Abstract: Detailed presentation of gas turbine capabilities to handle a variety of fuels including low Btu gases, distillate fuels and heavy liquid fuels. Discussed fuel specifications, pretreatment processes and capabilities, and associated turbine maintenance problems.

F-014

Hefner, W. J., Lordi, F. D., "PROGRESS IN HEAVY FUELS", Gas Turbine Division, General Electric Company, 1979, GER-3110A.

Abstract: The paper presents the various operational and environmental aspects of burning heavy oils in industrial gas turbines. Areas include turbine design, fuel additives, accessory system, turbine combustion deposits, emission controls and environmental regulations.

F-015

Freider, A. J., Felix, P. C., Hess, H. J., "EXPERIENCES WITH GAS TURBINES BURNING NON-REFINED FUEL OILS AND REALTED THEORETICAL INVESTIGATIONS", BST Brown Boveri-Sulzer Turbomachinery Limited, presented at the Gas Turbine Conference and Products Show, Zurich, Switzerland, March 20 - April 4, 1974, American Society of Mechanical Engineers Publication 75-GT-12.

Abstract: This paper presents experience on large, low firing temperature European gas turbines operating on crude and residual fuels. The most economic fuel can be a distillate a heavy distillate, a crude oil, and, in some applications, even a residual fuel.

F-016

Hetner, William J., "ALTERNATE FUELS CAPABILITY OF GAS TURBINES IN THE PROCESS INDUSTRY", General Electric Company, persented at the General Electric Gas Turbine State of the Art Engineering Seminar, June 20-23, 1976, Saratoga Springs, New York, ISOA-2-76.

Abstract: As we move into the latter 1970's and early 1980's, we can anticipate a period of continuing uncertainty in availability of fuel supplies for the process industry. Even though the overall picture is unclear, there are some aspects of the total problem that are predictable, with a reasonable degree of confidence. One of the developments that can be predicted on the domestic scene is the unavailability of natural gas as an industrial fuel. Short supplies of this resource have significantly limited the installation of new facilities utilizing natural gas as a fuel supply, as well as creating a need to convert existing equipment to use alternate supplies of fuel where uninterruptable sources of natural gas are no longer available.

This paper discusses the fuel flexiblity of heavy-duty gas turbines and is a status report on the capability of today's equipment. In addition, techniques for evaluating alternate gas turbine fuels, including requirements for cleanliness, combustion properties, physical properties, composition, performance and emissions characteristics, etc., are discussed. Fuels which are covered include:

- Gasification Process Derived Fuels
- By-Product Gases
- Crude Oil
- Residual Oil
- Vaporized Liquid Fuels
- Liquefied Coal Products

F-017

Patterson, John, R. "HEAVY-DUTY GAS TURBINE EXPERIENCE USING HEAVY FUELS", General Electric Company, presented at the General Electric Gas Turbine State of the Art Engineering Seminar, September 16, 17 and 18, 1974, Saratoga Springs, New York, ISOA-13-74.

Abstract: The purpose of this paper is to discuss the operating experience of General Electric HDGI using heavy liquid fuel in base load power generation service for an industrial plant. The operating statistics of the Rhone Progil chemical plant will be utilized in this discussion to show the viability of heavy liquid fuel fired gas turbines in base load industrial service and to show the favorable results of planned maintenance programs on availability and forced outage rate.

F-018

Patterson, J. R., "OPERATING AND MAINTENANCE EXPERIENCE FOR BASE LOAD GAS TURBINES USING HEAVY FUELS - A CASE STUDY", General Electric Company, presented at the Gas Turbine Conference and Products Show, Houston, Texas, March 2-6, 1975. American Society of Mechanical Engineers Publication 75-GT-74.

Abstract: This paper reviews the operating and maintenance experience of heavy fuel fired gas turbines used for base load power generation in an industrial complex. The data presented are based on over a quarter of a million fired hours of heavy fuel burning experience for ten gas turbines located in the Rhone Progil chlorine plant of Pont-de-Claix, France. A brief description of the turbine being studied and the arrangement of the power generation equipment in the chlorine plant is given. Three prime factors affecting maintenance/operation of the plant are discussed: physical and chemical properties of the fuel; environmental conditions of the site; and a mode of operation for the power generation equipment. A description of the type of maintenance inspections performed on the gas turbine is given in detail. The logged maintenance data for the plant is discussed as well as the maintenance performed on both the turbine and the turbine auxiliary components. Specific data are presented showing the causes of the forced outages and the year by year availability from the time of commissioning through 1973.

F-019

"STANDARDS OF PERFORMANCE FOR STATIONARY GAS TURBINES", 40 Code of Federal Regulations, Part 60, Subpart GG, paragraph 60,330, Federal Register 52798, September 10, 1979.

Abstract: Presents the allowable air pollution emission rates for stationary gas turbines with heat input at peak load equal to or greater than 10.7 gigajoules per hour. Applicable for new sources for which construction commenced after September 10, 1979.

F-020

Bittker, D. A., NASA/ Lewis, "AN ANALYTICAL STUDY OF NITROGEN OXIDES AND CARBON MONOXIDE EMISSIONS IN HYDROCARBON COMBUSTION WITH ADDED NITROGEN--PRELIMINARY RESULTS", Presentation at the Gas Turbine Conf., New Orleans, LA., March 13, '80.

Abstract:

This work is one part of a four-part Critical Research and Technology Fuels Combustion Program funded by the Department of Energy. The primary objective of this part of the program is to analytically determine the effect of combustor operating conditions on the conversion of fuel-bound nitrogen (FBN) to nitrogen oxides (NO_x). The effect of FBN and of operating conditions on carbon monoxide (CO) formation was also studied.

F-021

Bauserman, G. W., and A. Cohn, Westinghouse Electric Corp. and EPRI, "COMBUSTION EFFECTS OF COAL LIQUID AND OTHER SYNTHETIC FUELS IN GAS TURBINE COMBUSTORS--PART II: FULL SCALE COMBUSTOR AND CORROSION TESTS, Presentation at the Gas Turbine Conf., New Orleans, LA., March 10-13, 1980.

Abstract:

Combustion tests on over twelve types of coal derived liquid fuels from the EDS, H-coal, SRC-I and SRC-II processes and three shale oil fuels have been conducted in gas turbine type combustors. Emission measurements were made of NO_x, smoke, CO, and unburned hydrocarbons. Combustor wall temperature profiles were measured. The results are correlated with the fuel properties - percent nitrogen, hydrogen and aromaticity. This paper (Part II) describes the results of full scale combustor testing and of a long-term corrosion/deposition test. A companion paper by Cohn, et al. Part I discusses the fuels used in the program and the subscale combustor test results.

F-022

Singh, P. P., et al, Westinghouse Electric Corp., EPRI, and Mobil Res. and Dev. Corp., "COMPARATIVE TESTING OF PETROLEUM SURROGATE FUELS WITH COAL-DERIVED LIQUIDS IN A COMBUSTION TURBINE BURNER", Presentation at the Gas Turbine Conf., New Orleans, LA, March 10-13, 1980.

Abstract:

Tests have been made in a combustion turbine burner using six petroleum-derived surrogate (PDS) fuels simulating six coal-derived liquid (DCL) fuels tested earlier. The purpose being to examine their suitability for use in place of scarce CDL fuels for combustor development. The PDS and DCL fuels were matched in terms of aromaticity and fuel bound nitrogen although differences in viscosity, distillation range and constituent species existed. In three cases, the low fuel bound nitrogen present in the PDS fuels was made equal to their coal liquid counterparts via the addition of quinoline. All six PDS fuels were evaluated on a 0.14-m-dia combustor while one of the surrogate fuels was evaluated on a 0.3-m-dia Westinghouse commercial combustor.

F-023

Liu, T. M., R. M. Washam, Jet Propulsion Lab. and General Electric Co., "SMOKE CHARACTERISTICS OF DISTILLATE AND RESIDUAL FUEL BURNING IN GAS TURBINE COMBUSTORS", Presentation at the Gas Turbine Conf., New Orleans, LA, March 10-13, 1980.

Abstract:

During the development of a rich-lean staged dry low NO_x combustor, the conventional trend of increasing smoke with increasing operating equivalence ratio was found when tests were run with distillate fuel (%H = 13.0). However, when tests were run with residual fuel (%H = 11.4), the trend was reversed. In addition, when the same combustor was run with blends of distillate fuel and residual fuel, a drastic improvement of smoke was observed when only 6 percent of residual fuel was mixed with distillate fuel, and for any blending of more than 10 percent of residual fuel the combustor was practically smoke free. A chemical analysis of fuel samples revealed an appreciable amount of trace metals in the residual fuel, giving rise to the suspicion that the smoke reduction may have been due in part to these trace metals. Of these elements found, vanadium is believed to be the most likely to cause smoke reduction because of its relatively high concentration.

F-024

Naegeli, D. W., C. A. Moses, Southwest Research Institute, "EFFECT OF FUEL MOLECULAR STRUCTURE ON SOOT FORMATION IN GAS TURBINE ENGINES", Presentation at the Gas Turbine Conf., New Orleans, LA, March 10-13, 1980.

Abstract:

A high-pressure research combustor operating over a wide range of burner inlet conditions was used to determine the effects of fuel molecular structure on soot formation. Six test fuels with equal hydrogen content (12.8 percent) were blended to stress different molecular components and final boiling points. The fuels containing high concentrations (20 percent) of poly-cyclic aromatics and partially saturated polycyclic structures such as tetralin, produced more soot than would be expected from a hydrogen content correlation for typical petroleum based fuels. However, fuels containing naphthenes, such as decalin, agreed with the hydrogen content correlation. The contribution of polycyclic aromatics to soot formation was equivalent to a reduction in fuel hydrogen content of about one percent. The fuel sensitivity to soot formation due to the polycyclic aromatic contribution decreased as burner inlet pressure and fuel/air ratio increased.

F-025

Blazowski, W. S., A. F. Sarofim, J. C. Keck, Exxon Research and Engineering Co., and MIT, "THE INTERRELATIONSHIP BETWEEN SOOT AND FUEL NO_x CONTROL IN GAS TURBINE COMBUSTORS", Presentation at the Gas Turbine Conf., New Orleans, LA., March 10-13, 1980.

Abstract:

The decreased hydrogen content of future fuels will lead to increased formation of soot, while increased organically bound nitrogen in the fuel can result in excessive NO_x emission. Control concepts for these two problems are in conflict: prevention of soot requires leaner operation while control of emissions from fuel nitrogen requires fuel-rich operation. However, recent results of two DOE research programs point to both processes having a major dependence on "hydrocarbon breakthrough." Control of both fuel nitrogen conversion and soot formation can be achieved by primary zone operation at equivalence ratios just below that for hydrocarbon breakthrough. This paper reviews the evidence for the importance of hydrocarbon breakthrough, explains our current understanding of why hydrocarbon breakthrough is important, and offers suggestions of how these results might be applied.

F-026

Singh, P. P., A Cohn, et al, Westinghouse Electric Corp., Mobil Res. and Dev. Corp. and EPRI, "COMBUSTION EFFECTS OF COAL LIQUID AND OTHER SYNTHETIC FUELS IN GAS TURBINE COMBUSTORS--PART I: FUELS USED AND SUBSCALE COMBUSTION RESULTS",

Abstract:

Combustion tests on over twelve types of coal derived liquid fuels from the EDS, H-coal, SRC-I and SRC-II processes and three shale oil fuels have been conducted in gas turbine type combustors. Emission measurements were made of NO_x, smoke, CO, and unburned hydrocarbons. Combustor wall temperature profiles were measured. The results are correlated with the fuel properties-percent nitrogen, hydrogen and aromaticity. This part of the paper discusses the fuels used in subscale combustion tests along with the test results. A companion paper (Part II) describes the results of full-scale combustor tests and a long term corrosion/deposition test.

F-027 (Microfiche)

Chappell, G. A., Esso Res. and Eng. Co., Linden, N. J., "DEVELOPMENT OF THE AQUEOUS PROCESSES FOR REMOVING NO_x FROM FLUE GASES", June 1973, NTIS: PB-226-512.

Abstract: A screening study was conducted to evaluate the capability of aqueous solutions to scrub NO_x from the flue gases emitted by stationary power plants fired with fossil fuels. The key findings discussed include: The addition of NO₂ to flue gas to improve NO_x (mostly NO) absorption does not appear promising; Sulfite solutions and slurries are efficient NO₂-SO₂ absorbents; Calcium, magnesium, and zinc hydroxide slurries are effective NO₂-SO₂ absorbers; Limestone (CaCO₃) is also a good NO-SO₂ absorbent for the same reasons as for Ca(OH)₂; NO₂ scrubbing is enhanced by removing oxygen from the flue gas or by adding an anti-oxidant such as hydroquinone to the scrubbing solution; Sulfide solutions are excellent NO₂ and SO₂ absorbers but to generate a small amount of NO; and Part of the absorbed SO₂ is oxidized to sulfate. Combined NO_x-SO_x scrubbing seems feasible using any of several hydroxide or carbonate systems provided NO_x(NO) can be efficiently oxidized to NO₂ upstream from the scrubbing unit.

F-028 (Microfiche)

Lowell, P. S., Parsons, T. B. Radian Corp., Austin, Texas, "A THEORETICAL STUDY OF NO_x ABSORPTION USING AQUEOUS ALKALINE AND DRY SORBENTS", Final Report, December 1971, NTIS: PB-211 035.

Abstract: The study was carried out to develop a theoretical description of aqueous scrubbing processes for NO_x emission control.

F-029 (Microfiche)

Lowell, P. S., Parsons, T. B., Radian Corp., Austin, Texas, "A THEORETICAL STUDY OF NO_x ABSORPTION USING AQUEOUS ALKALINE AND DRY SORBENTS. VOLUME II", Final Report, December 1971, NTIS: PB-211 058.

Abstract: Technical notes pertaining to, and developed during, a study of the theoretical description of aqueous scrubbing processes for NO_x emission control are presented.

F-030 (Microfiche)

Chappell, G. A., Esso Res. and Eng. Co., Linden, N. J., DEVELOPMENT OF AQUEOUS PROCESSES FOR REMOVING NO_x FROM FLUE GASES-ADDENDUM", September 1972, NTIS: PB-212 858.

Abstract: The report summarizes the findings of a laboratory program for developing aqueous processes for removing NO_x and SO₂ from combustion flue gases. It discusses analytical techniques and scrubber design, as well as results obtained experimentally with a vertical spray tower scrubber.

F-031 (Microfiche)

Gouldin, F. C., Cornell Univ, Ithaca, N. Y., "CONTROLLING EMISSIONS FROM GAS TURBINES - THE IMPORTANCE OF CHEMICAL KINETICS AND TURBULENT MIXING", Nov. 1972, NTIS: PB-227 862

Abstract: An ideal combustor composed of a fuel-air mixing zone followed by a perfectly stirred reactor (PSE) and a series of plug-flow reactors is studied to determine emission levels of NO_x, CO, unburned hydrocarbons and soot.

F-032 (Microfiche)

Shimizu, A. B., et al, Acurex Corp., Mountain View, CA, "NO_x COMBUSTION CONTROL METHODS AND COSTS FOR STATIONARY SOURCES, SUMMARY STUDY", Sept. 1975, NTIS: PB-246 750.

Abstract: The report summarizes the technology, user experience, and cost for NO_x control from stationary combustion sources. It characterizes significant sources by equipment type, fuel consumption, and annual mass emission of NO_x. It summarizes NO_x control technology by combustion modification, fuel modification, flue gas treatment, and use of alternate processes. It identifies combustion modifications as the most advanced and effective technique for near-and-far term NO_x control. It gives available capital and differential operating costs for NO_x control in utility boilers by combustion modification and flue gas treatment.

F-033 (Microfiche)

EPRI, Palo Alto, CA, "THE PROCEEDINGS OF THE NO_x CONTROL TECHNOLOGY SEMINAR, HELD IN SAN FRANCISCO, CALIFORNIA ON FEB. 5-6, 1976", Feb. 1976, NTIS: PB-253-661/3ST.

Abstract: On February 5 and 6, 1976, EPRI sponsored a conference in San Francisco on the status of technology for control of oxides of nitrogen from power generation facilities coal-fired steam generators, gas turbines and synthetic fuel NO_x emissions were covered during the two-day seminar.

F-034 (Microfiche)

KVB Engineering, Inc., Tustin, CA, "REDUCTION ON NO_x THROUGH STAGE COMBUSTION IN COMBINED CYCLE SUPPLEMENTAL BOILERS, VOLUME I & 2, SYSTEMS OPTIMIZATION ANALYSES", Final Report, Feb. 1975, NTIS: PB-241 464 and PB-241 463/9ST.

Abstract: This report discusses an investigation directed to control of emissions from supplemental-fired combined cycles with the use of staged combustion in the steam generating portion of the system. The use of staged combustion provides conditions favorable for the occurrence of chemical reactions that result in a reduction of mass flow of nitric oxide (NO) present in the gas turbine exhaust.

C-3

F-035 (Microfiche)

Koutsoukos, E. P., et al, TRW Systems, Redondo Beach, CA, "ASSESSMENT OF CATALYSTS FOR CONTROL OF NO_x FROM STATIONARY POWER PLANTS, PHASE 1, VOLUME 1, Final Report, January 1975, NTIS: PB-239 745/3 ST.

Abstract: The report summarizes results of investigations to assess the technical and economic feasibility of using catalytic processes in power plant nitrogen oxide (NO_x) emission abatement. The investigations involved a literature survey and the development of a data bank on pertinent articles and patents, experimental screening tests on selected promising catalysts, and preliminary design and cost analysis of candidate processes adapted to new and/or existing power plants.

F-036 (Microfiche)

Hunter, S. C., et al, KVB, Inc., Tustin, CA, "APPLICATION OF COMBUSTION MODIFICATIONS OF INDUSTRIAL EQUIPMENT", Final Report, January 1979, NTIS: PB-294 214/2ST.

Abstract: The report gives results of a field test program to evaluate the effect of minor combustion modifications on pollutant emissions from a variety of industrial combustion equipment types. Tested were 22 units, including refinery process heaters; clay and cement kilns; steel and aluminum furnaces; boilers burning black liquor, wood bark, and CO gas; internal combustion engines; and gas-turbine combined cycles.

F-037 (Microfiche)

Crawford, A. R., et al, Exxon Research and Eng. Co, Linden, N.J., "CONTROL OF UTILITY BOILER AND GAS TURBINE POLLUTANT EMISSIONS BY COMBUSTION MODIFICATION-PHASE I", March 1978, NTIS: PB-281 078/6ST.

Abstract: The report gives results of a field study to assess the applicability of combustion modification techniques to control NO_x and other pollutant emissions from utility boilers and gas turbines without causing deleterious side effects. Comprehensive, statistically designed tests were used to evaluate the effect of combustion modifications.

F-038 (Microfiche)

Evans, R. M., et al, Acurex Corp., Mountain View, CA, "CONTROL TECHNIQUES FOR NITROGEN OXIDES EMISSIONS FROM STATIONARY SOURCES - SECOND EDITION", Final Report, January 1978, NTIS: PB-280 034/0ST.

Abstract: This second edition of Control Techniques for Nitrogen Oxides Emissions from Stationary Sources (AP-67) presents recent developments of nitrogen oxides (NOs) control techniques which have become available since preparation of the first edition.

F-039 (Microfiche)

Ando, Jumpei, et al, PEDCO-Environmental, Inc., Cincinnati, Ohio, "NOx ABATEMENT FOR STATIONARY SOURCES IN JAPAN", Final Report, Sept. 1977, NTIS: PB0276 948/7ST

Abstract: The report describes the status of NOx abatement technology for stationary sources in Japan as of August 1976. The report emphasizes flue gas treatment processes for control of NOx and SOx from flue gases.

F-040 (Microfiche)

Clay, D. T., and S. Lynn, Calif. Univ., Berkeley, CA., "DEVELOPMENT OF A FEASIBLE PROCESS FOR THE SIMULTANEOUS REMOVAL OF NITROGEN OXIDES AND SULFUR OXIDES FROM FOSSIL FUEL BURNING POWER PLANTS", June, 1974, NTIS: LBL-3059.

Abstract: A dry solids process has been developed for the simultaneous removal of NO and SO2 from power plant stack gases. A catalyst/absorbent in a net reducing flue gas effects the removal of SO2 by absorption as ferrous sulfide or sulfate and the removal of NO by reduction to nitrogen or ammonia.

F-041 (Microfiche)

Thomas, T. P., et al, Allied Chemical Corp., Idaho Falls, Idaho, "REDUCTION OF NOx WITH AMMONIA OVER ZEOLITE CATALYSTS", 1974, NTIS: CONF-7406]4-4.

Abstract: see: NSA 30 08, number 23350.

F-042 (Microfiche)

Mosier, Stanley A., et al, Pratt and Whitney Aircraft, W. Palm Beach, FLA, "LOW-POWER TURBOPROPULSION COMBUSTOR EXHAUST EMISSIONS, VOLUME III ANALYSIS", Final technical report, July, 1974, NTIS: AD-784 900/3

Abstract: The exploratory development effort to formulate and develop a computerized theoretical model to predict emission characteristics of gas turbine combustors and to identify, evaluate, and demonstrate improved combustion design techniques for increasing combustion efficiency at part power operating conditions was expanded to include detailed computer model and experimental data analyses. The generalized combustor computer program was used to predict exhaust emission concentrations from five different gas turbine engine burners; predictions were then compared with measured data. In general, excellent agreement was achieved.

F-043 (Microfiche)

Marchionna, N. R., et al, National Aeronautics and Space Admin., Lewis Res. Center, Cleveland, Ohio, "EFFECT OF WATER INJECTION ON NITRIC OXIDE EMISSIONS OF A GAS TURBINE COMBUSTOR BURNING NATURAL GAS FUEL", Dec. 1973, NTIS: N74-14651-5.

Abstract: The effect of direct water injection on the exhaust gas emissions of a turbojet combustor burning natural gas fuel was investigated. The results are compared with the results from similar tests using ASTM Jet-A fuel. Increasing water injection decreased the emissions of oxides of nitrogen (NOx) and increased the emissions of carbon monoxide and unburned hydrocarbons.

F-044 (Microfiche)

Metzler, A. J., NASA/Lewis, Cleveland, Ohio, "CONTROL OF NITROGEN DIOXIDE IN STACK EMISSION BY REACTION WITH AMMONIA", March 1971, NTIS: N71-20267.

Abstract: Research rocket operations released nitrogen dioxide (NO₂) containing stack gases to the atmosphere. To eliminate the potential hazard of this release, a gas-phase reactor system was developed which used anhydrous ammonia to convert the NO₂ to ammonium nitrate.

F-045 (Microfiche)

Lorimer, D. H., Cal. Univ., Berkeley, Lawrence Berkeley Lab., "REDUCTION OF NITRIC OXIDE BY CARBON MONOXIDE OVER A SILICA SUPPORTED PLATINUM CATALYST: INFRARED AND KINETIC STUDIES", July 1978, NTIS: LBL-8007.

Abstract: The reduction of nitric oxide by carbon monoxide over a 4.5 Wt.% platinum catalyst supported on silica was studied at 300°C. Reaction rate data was obtained together with in situ infrared spectra of species on the catalyst surface.

F-046 (Microfiche)

Mularz, E. J., et al, NASA/Lewis, Cleveland, OH, "POLLUTION EMISSIONS FROM SINGLE SWIRL-CAN COMBUSTOR MODULES AT PARAMETRIC TEST CONDITIONS", January, 1975, NTIS: N75-15200/9ST.

Abstract: Exhaust pollutant emissions were measured from single swirl-can combustor modules operating over a pressure range of 69 to 276 N/sq cm (100 to 400 psia), over a fuel-air ratio range of 0.01 to 0.04, at an inlet air temperature of 733 K (860 F), and at a constant reference velocity of 23.2 m/sec.

F-047 (Microfiche)

Roffe, G., and A. Ferri, Advanced Technology Labs., Inc., Westbury, N.Y., "PREVAPORIZATION AND PREMIXING TO OBTAIN LOW OXIDES OF NITROGEN IN GAS TURBINE COMBUSTORS", Final Report, March 1975, NTIS: N75-17362/5ST.

Abstract: Tests were conducted to determine the effectiveness of prevaporization and premixing in reducing the formation of oxides of nitrogen in a gas turbine type combustor using liquid JP-5 fuel at the supersonic cruise condition.

F-048 (Microfiche)

Roffe, G., General Applied Science Labs., Inc., Westbury, N.Y., "EFFECT OF INLET TEMPERATURE AND PRESSURE ON EMISSION FROM A PREMIXING GAS TURBINE PRIMARY ZONE COMBUSTOR", Final Report, Sept. 1976, NTIS: N76-33208/9ST.

Abstract: Experiments were conducted to determine the performance of a premixing prevaporizing gas turbine primary zone combustor design over a range of combustor inlet temperatures from 700-1000 K and a range of inlet pressures from 40-240 N/sq cm.

F-049

Faucett, H. L., et al, Tenn. Valley Authority, Muscle Shoals, ALA, "TECHNICAL ASSESSMENT OF NO_x REMOVAL PROCESSES FOR UTILITY APPLICATION", Final Report, March 1978, NTIS: EPRI-AF-568.

Abstract: A state-of-the-art review of the processes currently being developed for the removal of nitrogen oxides (NO_x) from power plant stack gas was conducted. The major sections in each technical evaluation for each process included detailed process description containing a simplified block flow diagram, the current status of development of the process, the raw material and utility requirements, the published economics, the technical and environmental considerations, and the overall advantages and disadvantages of the process.

F-050 (Microfiche)

KVB Engineering, Tustin, CA, "REDUCTION OF NO_x THROUGH STAGED COMBUSTION IN COMBINED CYCLE SUPPLEMENTAL BOILERS", Volume 1, February 1975, NTIS: PB-241-463.

F-051 (Microfiche)

Hurley, J. F., and S. Herish, "EFFECT OF SMOKE AND CORROSION SUPPRESSANT ADDITIVES ON PARTICULATE AND GASEOUS EMISSIONS FROM A UTILITY GAS TURBINE", Final Report, KVB, Inc., Scarsdale, N.Y., March 1977, NTIS: EPRI-FP-398.

F-052

McCutchen, G. D., EPA, "NO_x EMISSION TRENDS AND FEDERAL REGULATION", Presentation at: AICHE, 69th annual meeting November/December 1976.

Abstract: At present regulatory levels, national nitrogen oxide (NO_x) emissions from stationary sources are projected to increase 66 percent. Applying best technology to all new sources would slow, but not stop, this increase, a situation due more to low levels of available control technology than to rapid growth. A multi-pronged regulatory strategy is needed to reverse this upward trend.

F-053

Lisauskas, R. A., S. A. Johnson, "NO_x FORMATION DURING GAS COMBUSTION", Riley Stoker Corp., Worcester, Mass.; in CEP, August 1976.

Abstract: The overall conversion of coal nitrogen to NO_x in a gasification/combustion process was found to be significantly lower than that which occurs in the direct burning of pulverized coal.

F-054

Gasparovic, No., J. D. Stapersma, "GAS TURBINES WITH HEAT EXCHANGER AND WATER INJECTION IN THE COMPRESSED AIR", Article in COMBUSTION, December 1973, from "Brennstoff-Waerme-Kraft, June 1973.

Abstract: In gas turbine plants with heat exchanger, water injection into the compressed air between the compressor and the heat exchanger only marginally increases the efficiency but it substantially raises output, regarded from the point of view of energy economics, by as much as 55% in two-shaft plants. The specific cost is thus reduced as compared with simple gas turbines without heat exchanger. Regulation of the water supply presents to difficulty. The transient behavior is discussed. The addition of water to the cycle reduces the emission of nitrogen oxides by at least half.

F-055

23 Articles from Magazines: DESULFURIZATION.

- 1) THE THOROUGHbred 101 DESULFURIZATION PROCESS CEP, May 1975, Japan, Chiyoda Ch.E & C. Co.
- 2) EPA/RTP PILOT STUDIES RELATED TO UNSATURATED OPERATION OF LIME AND LIMESTONE SCRUBBERS, Combustion, October 1975, EPA.
- 3) RELIABILITY OF FLUE GAS DESULFURIZATION SYSTEMS, Combustion, October 1975, General Electric Company.
- 4) STACK GAS SCRUBBING - THE "CON" VIEWPOINT, Combustion October 1975, American Electric Power Service Corporation.
- 5) DETAILED COST ESTIMATES FOR ADVANCED EFFLUENT DESULFURIZATION PROCESS, Combustion, October 1975, TVA.

- 6) STATUS AND PROBLEMS OF REGENERABLE FLUE GAS DESULFURIZATION PROCESSES, Journal of the Air Pollution Control Association, September 1976, Battelle.
- 7) SO₂ SCRUBBER PASSES TEST AT FIRESTONE, Pollution Engineering, April 1977, Firestone Tire and Rubber Company.
- 8) SO₂ SCRUBBING, CLEANING THE AIR, Environmental Science & Technology, January 1978, EPA.
- 9) ALTERNATIVES FOR STACK GAS DESULFURIZATION BY THROWAWAY SCRUBBING, CEP, February 1978, University of California, Berkeley.
- 10) THE KELLOGG/WEIR SCRUBBING SYSTEM, CEP, February 1978, Pullman Kellogg.
- 11) LIME - LIMESTONE SCRUBBING: DESIGN CONSIDERATIONS, CEP, February 1978, SAS Corporation.
- 12) JET BUBBLING FLUE GAS DESULFURIZATION, CEP, February 1978, Chiyoda Ch.E & C. Co., Japan.
- 13) THE THIOSORBIC FLUE GAS DESULFURIZATION PROCESS, CEP, February 1978, Dravo Corporation.
- 14) THE COLSTRIP FLUE GAS CLEANING SYSTEM, CEP, February 1978, Montana Power Corp., Bechtel Power Corp., Combustion Equipment Assoc. Inc., A. D. Little Inc.
- 15) ADVANCED IN SO₂ STACK GAS SCRUBBING, CEP, February 1978, EPA.
- 16) EFFICIENCY AND RELIABILITY OF SULFUR DIOXIDE SCRUBBERS, Journal of the Air Pollution Control Association, July 1978, National Assoc. of Electric Companies.
- 17) DRY SCRUBBING LOOMS LARGE IN SO₂ CLEANUP PLANS, Chemical Engineering, August 1979 (News Feature).
- 18) LIME/LIMESTONE SCRUBBER OPERATION AND CONTROL, Journal of the Air Pollution Control Association, October 1979, Radian Corp. and EPRI.
- 19) SULFUR OXIDES REMOVAL BY WET SCRUBBING APPLICATION TO UTILITY BOILERS, Combustion, October 1975, Combustion Engineering, Inc.
- 20) ESTIMATING COSTS OF FLUE GAS DESULFURIZATION SYSTEMS FOR UTILITY BOILERS, Journal of the Air Pollution Control Assoc., March 1976, PEDCo - Environmental Specialists, Inc. and EPA.
- 21) U.S. UTILITIES CHALLENGED TO EMULATE JAPAN'S FGD SCRUBBER TECHNOLOGY, Journal of the Air Pollution Control Assoc., November 1978, Tech. News.
- 22) STATUS OF SCRUBBERS ON COAL-FIRED POWER PLANTS, December 1977, Journal Air Pollution Control Assoc., January 1979, Battelle and U.S. DOD.

- 23) TWO-STAGE, DRY FGD AND PARTICULATE REMOVAL SYSTEM, Journal Air Pollution Control Assoc., April 1979.

F-056

Five papers from Magazines: NITROGEN REDUCTION.

- 1) INFLUENCE OF COMBUSTION MODIFICATION AND FUEL NITROGEN CONTENT ON NITROGEN OXIDES EMISSIONS FROM FUEL OIL COMBUSTION, Combustion, August 1972, by Esso Res. and Eng. Co.
- 2) NO_x EMISSIONS FROM INDUSTRIALS BOILERS; POTENTIAL CONTROL METHODS, Combustion, October 1973, by Siegmund and Tumes, ASME Conference, May 1973.
- 3) A WAY TO LOWER NO_x IN UTILITY BOILERS, Environmental Science & Technology, PAT - Report March 1977, Exxon Res. and Eng. Company.
- 4) A NEW CATALYTIC REACTOR FOR NITROGEN OXIDES REMOVAL, Journal of the Air Pollution Control Association, October 1979, Hitachi Ltd. Japan.
- 5) SELECTIVE REDUCTION OF NITROGEN OXIDES IN COMBUSTION FLUE GASES, Journal of the Air Pollution Control Association, Hitachi Ltd., Japan.

F-057

Dusatko, G., "TAUNTON MUNICIPAL LIGHTING PLANT", Particulate Emissions Test Program, by KVB, Report No. 18400-666, July 1978.

Abstract: A series of particulate emissions tests were conducted by KVB Inc. at the Cleary/Flood Station, Taunton Municipal Light Company, located in Taunton, Massachusetts. The purpose was to demonstrate compliance with emission limitations of 0.12 lbs/10 Btu adopted by the Southeastern Massachusetts Air Pollution Control District. Number 6 fuel oil with a nominal sulfur content of 0.9% was burned in both the gas turbine and boiler during the test period.

This report contains the results of the tests and associated documentation of the raw data, reduced data and test conditions. Applicable pretest data, field test data and reduced data are presented in the appendices. The fuel analysis presented in this report shows results of individual samples taken during each particulate test for both the turbine and the boiler.

F-058

Telles, A. J., "TURBINE EMISSION CONTROL, A SYSTEM APPROACH", Telles Environmental Systems Inc., Presentation at the 68th Annual Meeting Air Pollution Control Association, June 1975.

Abstract: An emission control system has been in operation on a 17000 lb. thrust jet engine test cell for the past 3 years. This study and control system installation was concerned primarily with the particulate and noise emissions.

F-059-N

"PROPOSED STANDARDS OF PERFORMANCE FOR STATIONARY GAS TURBINES", Volume 1 of Standard Support and Environmental Impact Statement, U.S. EPA, September 1977.

Abstract: Standard for NO_x and SO₂ emission.

F-060

Conser, R. E., "THE SHELL FLUE GAS DESULFURIZATION PROCESS: HOW DOES IT STACK UP?" UOP Process Division, Des Plaines, Illinois, Presentation at the Conference on Control of Gaseous Sulfur Compound Emission Salford, England, April 1973.

Abstract: SHELL Process description.

F-061

Robertson, D. J., R. H. Groth, A. G. Glastris, "HCN CONTENT OF TURBINE ENGINE EXHASUT", Article in Journal of the Air Pollution Control Assoc., from Pratt & Whitney Aircraft Group, East Hartford, Connecticut, January 1979.

Abstract: Experimental description, exhasut analysis and result discussion (1 page article).

F-062

Haebig, J. E., B. E. Davis, E. R. Dzuma, "PRELIMINARY SMALL-SCALE COMBUSTION TESTS OF COAL LIQUIDS", Gulf Research & Development Company, Pittsburgh, PA, Article in Environmental Science & Technology, No. 3, March 1976.

Abstract: Nonupgraded coal liquids contain high concentrations of nitrogen and aromatics; the tendency for such fuels to emit excessive amounts of NO_x and smoke was examined in burning tests in a modified 1-gph boiler equipped with an air-atomizing nozzle. Full-boiling range and distillate coal liquids were tested, and conventional nitrogen-doped petroleum fuel oils were used for comparison. At 80% excess air, the fraction of the fuel-bound nitrogen converted to NO_x was 80%, but the conversion decreased to 35% at 25% excess air. Petroleum oils exhibited similar behavior. Smoke levels from the full-range and distillate coal liquids were similar to those from petroleum No. 4 and No. 2 fuel oils, respectively. The use of a set of modified burners showed that increasing the air-fuel mixing rate decreased the smoke emissions, but increased the conversion of fuel-bound nitrogen.

F-063

Borgwaelst, R. H. "EPA/RTP PILOT STUDIES RELATED TO UNSATURATED OPERATION OF LIME AND LIMESTONE SCRUBBERS" in Combustion, by EPA, October 1975.

Abstract: An oddity of lime and limestone SO₂ scrubbers is the observation that they can run unsaturated during closed loop operation. Experimental studies of the

process conditions necessary to achieve unsaturated scrubbing liquor are reported, and a mechanism is proposed that accounts for it.

F-064

Tamaki, A., "THE THOROUGHbred 101 DESULFURIZATION PROCESS", Chyoda Chemical Engineering & Construction Co., Ltd., Japan, Article in Chemical Engineering Progress, May 1975.

Abstract: A dilute sulfuric acid-gypsum process is used to desulfurize flue gas for large utility boilers; removal of sulfur dioxide, as well as particulates, is achieved.

F-065

Albrecht, P. F., J. a. Lieberman, "RELIABILITY OF FLUE GAS DESULFURIZATION SYSTEMS", General Electric Company, Article in Combustion, October, 1975.

Abstract: Survey of full-scale desulfurization systems for power plants indicates they have potential for reliable operation but that their average availability has been very poor to date. In spite of this, utility commitments for additional desulfurizing capacity show an annual compound growth rate of 93% for the years 1971 through 1977.

F-066

Ruggeri, S., "STACK SCRUBBING - THE "CON" VIEWPOINT, American Electric Power Service Corporation, Article in Combustion, October 1975.

Abstract: This paper consists of two parts. The first deals with removal of sulfur from coal in preference to removal of sulfur dioxide from stack gases. The second deals with the question of whether constant emission controls are necessary.

F-067

McGlamery, G. G. et al, "DETAILED COST ESTIMATES FOR ADVANCED EFFLUENT DESULFURIZATION PROCESSES", Tennessee Valley Authority, Article in Combustion, October 1975.

Abstract: A detailed, segmented, highly visible cost comparison of the five leading stack gas desulfurization processes was conducted. Using data available in late 1973, complete economic evaluations were prepared for scrubbing - regeneration to sulfuric acid, sodium solution scrubbing - SO₂ reduction to sulfur, and catalytic oxidation (Cat-Ox).

F-068

Murphy, S. M., H. S. Rosenberg, R. B. Engdahl, "STATUS AND PROBLEMS OF REGENERABLE FLUE GAS DESULFURIZATION", Battelle, Columbus Lab., Article in Journal of the Air Pollution Control Assoc., September 1976.

Abstract: This paper discusses briefly: (1) the announced status of the many regenerable FGD processes, (2) the problem of reductant gas supply, and (3) the effect on FGD processes of using coal based reducing gas instead of reformed natural gas.

F-069

Zaharchuk, R., L. K. Legatski, "SO₂ SCRUBBER PASSES TEST AT FIRESTONE", Firestone Tire and Rubber Company, FMC Corporation, Article in Pollution Engineering, April 1977.

Abstract: Since January 1975, a pilot plant for the removal of SO₂ and flyash has been in operation at Firestone Tire & Rubber Company's Pottstown, PA facility. The plant is producing 90 percent SO₂ removal efficiencies with a system availability of 94 percent and a flue gas capacity of 14,000 cfm.

F-070

ES&T Report, "SO₂ SCRUBBING CLEARING THE AIR", Environmental Science & Technology, January 1978.

Abstract: A Florida symposium covered numerous FGD technologies. But future emphasis may be on recoverable materials and salable by-products, as well as air cleanup.

F-071

Rochelle, G. T., C. J. King, "ALTERNATIVES FOR STACK GAS DESULFURIZATION BY THROW-AWAY SCRUBBING", University of California, Berkeley, Report in CEP, February 1978.

Abstract: Several promising alternatives in throwaway scrubbing have yet to be adequately explored.

F-072

Raymond, W. J., A. G. Sliger, "THE KELLOGG/WEIR SCRUBBING SYSTEM", Pullmann Kellogg, CEP, February 1978.

Abstract: When coal containing nearly 5% sulfur is being used, this system can remove more than 92% of the SO₂ in the entering flue gas.

F-072

Slack, A. V., "LIME-LIMESTONE SCRUBBING: DESIGN CONSIDERATIONS", SAS Corporation, Sheffield, Alabama, CEP, February 1978.

Abstract: Although removing SO₂ via lime or limestone scrubbing is a relatively simple process, there are a number of factors that present problems including scaling prevention, absorbent feed control, and mist eliminator efficiency.

F-074

Tolemura, H., T. Kensi, H. Yanagioka, "JET BUBBLING FLUE GAS DESULFURIZATION", Chyoda Chemical Eng. & Construction Co., Yokohama, Japan, CEP, February 1978.

Abstract: Among the features of this SO₂ removal system are low investment and operating costs, and easy, stable operation without scaling.

F-075

Selmercsi, J. G., D. A. Stewart, "THE THIOSORBIC FLUE GAS DESULFURIZATION PROCESS", Drvo Corporation, Pittsburgh, PA, CEP, February 1978.

Abstract: Thiosorbic scrubbing liquor is capable of carrying 10 to 15 times as much dissolved alkalinity in solution as conventional calcium-based process liquors.

F-076

Grimm, Abrams, Leffmann, Raben, LeManitie, "THE COLSTRIP FLUE GAS CLEANING SYSTEM", The Montana Power Company, Bechtel Power Corporation, Combustion Equipments Assoc., Inc., Arthur D. Little, Inc., CEP, February 1978.

Abstract: Two years of operation have shown that with a particular class of western coal, flue gas desulfurization can be accomplished using the alkali in the coal's fly ash.

F-077

Princiotta, F. T., "ADVANCED IN SO₂ STACK GAS SCRUBBING", EPA, Washington, D.C., CEP, February, 1978.

Abstract: Of the emerging technologies, atmospheric fluidized-bed combustion appears the most attractive because of its relatively simple concept and its low operating costs.

F-078

Megonnell, W. H., "EFFICIENCY AND RELIABILITY OF SULFUR DIOXIDE SCRUBBERS", National Assoc. of Electric Companies, Journal of the Air Pollution Control Assoc., July 1978.

Abstract: This paper is concerned with the companies which have already made firm scrubber commitments and significant investments in this particular control technology.

F-079

Chemical Engineering News, "DRY SCRUBBING LOOMS LARGE IN SO₂ CLEANUP PLANS", Chemical Engineering, August 1979.

Abstract: The latest standards on SO₂ emissions from new coal-fired utilities favor the use of dry scrubbing, which, according to its supporters, boasts lower investment and operating costs and avoids sludge-disposal problems.

F-080

Gaginani, M. R., P. G. Maruin, "SULFUR OXIDES REMOVAL BY WET SCRUBBING APPLICATION TO UTILITY BOILERS", Abstracted from a presentation at Frontiers of Power Technology conference Stillwater Oklahoma, October 1975, Combustion.

Abstract: This paper continues C-E's policy of open discussion. In addition, advances in wet-scrubber technology and the verification of theory by experience enable us to present a system design with availability and reliability as its aim.

F-081

Oxley, J. H., D. R. Israel, "STATUS OF SCRUBBERS ON COAL-FIRED POWER PLANTS, Battelle Laboratories, U.S. DOD, Journal of the Air Pollution Control Assoc., January 1979.

Abstract: Battelle was asked to perform field assessments during the last two weeks of 1977 of five scrubber operations which were believed to typify the best available technology in the U.S.

F-082

Reisinger, A. A., D. C. Gehri, "TWO-STAGE, DRY FGD AND PARTICULATE REMOVAL SYSTEM", Wheelabrator-Frye Inc., Rockwell International, Journal of the Air Pollution control Assoc., April 1979.

Abstract: Two proven technologies have been combined in the development of a system for the removal of SO₂ from the flue gases of fossil fired boilers. The major components of this system are a spray dryer contractor and a fabric filter particulate collector. The spray dryer provides the means of primary SO₂ removal. The fabric filter collects fly ash and dry products of removal, and it also provides secondary SO₂ removal.

F-083

Jones, D. G., O. W. Hargrove, T. M. Morasky, "LINE/LIMESTONE SCRUBBER OPERATION AND CONTROL" Ardian Corporation and EPRI, Journal of the Air Pollution Control Assoc., October 1979.

Abstract: This paper examines operating and control experience obtained at full-scale lime-limestone scrubber systems both in the eastern and western United States.

F-084

Devitt, T. W., C. J. Catlynne, "ESTIMATING COSTS OF FLUE GAS DESULFURIZATION SYSTEMS FOR UTILITY BOILERS", PEDCo - Environmental Specialists Inc., and EPA, Journal of the Air Pollution Control Assoc., March 1976.

Abstract: This paper presents an overview of the status and costs of flue gas desulfurization (FGD) systems, and the factors relating to the variability in costs. It is based in part upon work performed in developing detailed FGD cost estimating manuals for EPA.

F-085 Microfiche

Jumpei, Ando et al, "SO₂ ABATEMENT FOR STATIONARY SOURCES IN JAPAN", "NO ABATEMENT FOR STATIONARY SOURCES IN JAPAN", PEDCo - Environmental Specialists, Inc., Cincinnati, Ohio, January 1976, NITS: EPA/6002-76/013A and -/013B.

Abstract: Japanese NO_x and NO_x/SO₂ abatement summarized in two separate reports. Control technology and economics.

F-086

Turner, D. W., R. L. Andrews, C. W. Siegmund, "INFLUENCE OF COMBUSTION MODIFICATION AND FUEL NITROGEN CONTENT IN NITROGEN OXIDES EMISSION FROM FUEL OIL COMBUSTION", Esso Research and Engineering Company, Presentation of AIChE, Combustion, August 1972.

Abstract: Esso Research has carried out a study to determine the extent of fuel nitrogen conversion and the degree of control possible with combustion modification.

F-087

Siegmund, C. W., D. W. turner, "NO_x EMISSIONS FROM INDUSTRIAL BOILERS: POTENTIAL CONTROL METHODS", Presentation at the ASME Industrial Power Conf., May 1973, Combustion, October 1973.

Abstract: Low excess air and flue gas recycle can control NO_x from thermal fixation. Two stage combustion controls both thermal and fuel NO_x.

F-088

PAT-Report, "A WAY TO LOWER NO_x IN UTILITY BOILERS", in Environmental Science & Technology, March 1977.

Abstract: The Exxon thermal deNO_x process reduced emissions 50% and worked at full load on a refinery in Japan.

F-089

Ootsuka, K., M. Mukai et al, "A NEW CATALYTIC REACTOR FOR NITROGEN OXIDES REMOVAL" from Hitachi and Babcock - Hitachi, Japan, Journal of the Air Pollution Control Asso., October 1979.

Abstract: The information presented in this paper is concerned with catalytic NO_x removal reactor for a dirty (containing dust) flue gas.

F-090

Matsuda, S., T. Narta, et al, "SELECTIVE REDUCTION OF NITROGEN OXIDES IN COMBUSTION FLUE GASES", from Hitachi and Babcock - Hitachi, Journal of the Air Pollution Control Asso., January 1979.

Abstract: The information presented in this paper is concerned with the removal of NO_x in combustion flue gases. A catalytic process for the selective reduction of nitrogen oxides by ammonia has been investigated. Efforts were made toward the development of catalysts resistant to SO_x poisoning.

F-091

Bunker, W. W., "GAS TURBINE CATALYTIC COMBUSTORS FOR COAL DERIVED FUELS", Department of Energy, Washington, D.C., Sec. Rept. No. CONF-781109--(LOV. 1), September 1979.

Abstract: On-going programs for the combustion of low Btu gas, medium Btu gas, and heavy liquids are described. Future plans for possible field tests are discussed.

F-092

Clark, J. S., C. E. Lowell, R. W. Niedzwiecki, J. J. Nainiger, "GAS-TURBINE CRITICAL RESEARCH AND ADVANCED TECHNOLOGY SUPPORT PROJECT", NASA-TM--79139, June 1979.

Abstract: The technical progress made during the first 15 months of a planed 40-month project to provide a critical-technology data base for utility gas-turbine systems capable of burning coal-derived fuels is reported.

F-093

Hubleyu, J. F., S. Hersh, "EFFECT OF SMOKE AND CORROSION SUPPRESSANT ADDITIVES ON PARTICULATE AND GASIOUS EMISSIONS FROM A UTILITY GAS TURBINE", KVB, Inc., Scarsdale, New York, Report No. EPRI-EP--398, March 1977.

Abstract: Metallic based fuel additives are widely used for the suppression of visible exhaust smoke and inhibition of hot section corrosion in electric utility gas turbines.

F-094

Sims, C. T., "HIGH TEMPERATURE GAS TURBINE ENGINE COMPONENT MATERIALS TESTING PROGRAM", General Electric Co., Schenectady, N.Y., Report No. FF--1765-42, February 1978. **Abstract:** Results from the completed initial coal-derived liquid fuel tests are presented, and continue to be analyzed.

F-095

Carlson, N. G., "DEVELOPMENT OF HIGH-TEMPERATURE SUBSYSTEM TECHNOLOGY TO A TECHNOLOGY READINESS STATE: PHASE I", United Technologies Corporation, Farmington, Conn., Report No. FE--2292-19, March 1977.

Abstract: The United States Energy Research and Development Administration is sponsoring a three phase program to develop and demonstrate the technology required for the efficient and environmentally acceptable use of coal-derived fuels in an industrial gas-turbine engine. The first phase of this program, Phase I, consisted of the program and subsystem definition. The Phase I design definition studies were directed primarily at achieving the critical objectives of high performance, durability, low risk, and acceptable emissions for the turbine and combustor subsystems.

F-096

Blazowski, W. S., R. B. Edelman, P. T. Harsha, "FUNDAMENTAL CHARACTERIZATION OF ALTERNATE FUEL EFFECTS IN CONTINUOUS COMBUSTION SYSTEMS", Exxon Research and Engineering Co., Linden, N. J., Report No. SAN--1543-12, September 11, 1978.

Abstract: The overall objective is to assist in the development of fuel-flexible combustion systems for gas turbines as well as rankine and stirling cycle engines. The primary emphasis of the program is on liquid hydrocarbons produced from non-petroleum resources.

APPENDIX B

SUPPLEMENTARY SYNFUEL PROPERTY DATA

The Fuel Properties tables contained in this appendix section represent analyses obtained from the literature search. They do not appear in the main report body but are appended as supplementary data.

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F			
HYDROGEN, WT %				VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				-100°F-175°	135		
NITROGEN TOTAL, WT %				-122°F-210°	43.65		
SULFUR TOTAL, WT %				-210°F-250°	16.84		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, Wt% Heptane Ins	19.			100°F			
OLEFINS, Wt% Benzene Ins.	6.2			122°F			
NAPHTHENES, VOL % DMF/Xylene Ins.	3.0			210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	1.4	ASTM		TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	395	ASTM D-1160					
10% EVAPORATED	510						
50% EVAPORATED	762						
90% EVAPORATED	945						
FINAL BOILING POINT	---						
RESIDUE, VOL %	30						
FLASH POINT, °F							
GRAVITY, °API	-5.7						
GRAVITY, SPECIFIC, 60°F	1.1248						
100°F							
210°F							
NOTES							

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-1

FUEL
PROPERTIES

FUEL TYPE Synthoil (Centrifuged)

FROM REFERENCE Char. of Coal Liquids

FE-2010-9

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	88.28			POUR POINT, °F	75		
HYDROGEN, WT %	7.42			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	2.27			100°F			
NITROGEN TOTAL, WT %	1.31			122°F 210°	56.20		
SULFUR TOTAL, WT %	0.56			210°F 250°	18.73		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL % Heptane Ins.	18.4			100°F			
OLEFINS, VOL % Benzene Ins.	4.4			122°F			
NAPHTHENES, VOL % DMF/Xylene Ins.	0.16			210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %	0.015	ASTM		JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TOR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al			
WATER & SEDIMENT, VOL %				As			
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca			
				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY				ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	445	ASTM D-1160					
10% EVAPORATED	552						
50% EVAPORATED	795						
70%-80% EVAPORATED	970						
FINAL BOILING POINT							
RESIDUE, VOL %	30						
FLASH POINT, °F	04.3						
GRAVITY, °API	1.1124						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
C1 10 ppm							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE Synthoil Washed Filtrate			
RMP JOB NO. 6009-1 TABLE B-2				FROM REFERENCE Characteristics of			
				Coal Liquids FE-2010-9			
				SHEET ____ OF ____			

COMPOSITION		TEST METHOD	FLUIDITY		TEST METHOD
CARBON, WT %	89.08		POUR POINT, °F		
HYDROGEN, WT %	9.47		VISCOSITY, KINEMATIC, cS		
OXYGEN, WT %	0.35		100°F		
NITROGEN TOTAL, WT %	0.376		122°F		
SULFUR TOTAL, WT %	0.02		210°F		
SULFUR, MERCAPTAN, WT %			VISCOSITY, SAYBOLT UNIV., SEC		
PARAFFINS, VOL % Heptane Ins.	3.88		100°F		
OLEFINS, VOL % Benzene Ins.	0.43		122°F		
NAPHTHENES, VOL %			210°F		
AROMATICS TOTAL, VOL %	89.8		COMBUSTION		
NAPHTHALENES, VOL %			NET HEAT OF COMB., BTU/LB		
POLYNUCLEAR AROMATICS, VOL %			GROSS HEAT OF COMB., BTU/LB		
CON. CARBON RESIDUE ON 10%, WT%	10.77		THERMAL STABILITY		
ON 100%, WT%			JFTOT, BREAKPOINT TEMP., °F		
ASH, WT %			TDR ΔP		
ASH MELT TEMPERATURE, °F			TRACE METAL ANALYSIS, PPM		
FILTERABLE DIRT, MG/100 ML			Al		ORIGINAL PAGE IS OF POOR QUALITY
WATER, VOL %			As		
WATER & SEDIMENT, VOL %			Ba		
WAX, WT %			Ca		
WAX, MELT TEMPERATURE, °F			Cd		
VOLATILITY			Cr, total		
DISTILLATION TEMP., °F MAX			Cu		
INITIAL BOILING POINT	380	ASTM D-1160	Fe, total		
10% EVAPORATED	495		Hg		
50% EVAPORATED	700		K		
80% 80% EVAPORATED	990		Mg		
FINAL BOILING POINT			Mn		
RESIDUE, VOL %			Mo		
FLASH POINT, °F			Na		
GRAVITY, °API	7.2		Ni		
GRAVITY, SPECIFIC, 60°F	1.0202		Pb		
100°F			Se		
210°F			Si		
NOTES			Ti		
			V		
			Zn		

FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-3

**FUEL
PROPERTIES**

FUEL TYPE Upgraded Synthoil

FROM REFERENCE Char. of Coal Liquids

FE-2010-9 SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	89.17			POUR POINT, °F			
HYDROGEN, WT %	9.77			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.33			100°F			
NITROGEN TOTAL, WT %	0.377			122°F			
SULFUR TOTAL, WT %	0.02			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %	87.0			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%	0.06			THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	463	ASTM D-1160					
10% EVAPORATED	565						
50% EVAPORATED	701						
90% EVAPORATED	863						
FINAL BOILING POINT	950						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	9.5						
GRAVITY, SPECIFIC, 60°F	1.0035						
100°F							
210°F							
NOTES							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE <u>Upgraded Synthoil Distillate</u>		FROM REFERENCE <u>Char. of Coal Liquids</u>	
RMP JOB NO. 6009-1				FE-2010-9		SHEET ____ OF ____	
TABLE B-4							

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COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL %
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT%
 ON 100%, WT%
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
~~WATER & SEDIMENT, VOL %~~ mg/l
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

0.1	
2.52	
31.6	

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

414	ASTM D-1160
472	
514	
592	
670	
235	ASTM D-56 (93)
13.6	Digital Density
	Meter

NOTES ND = Not detected of detection limit shown
 1) values are composite values from the 400-650°F and
 650°F+ analysis

FLUIDITY

POUR POINT, °F
 VISCOSITY, KINEMATIC, cS
 100°F 40°C
 122°F
 210°F
 VISCOSITY, SAYBOLT UNIV., SEC
 100°F
 122°F
 210°F

TEST METHOD

-45	ASTM D-97
4.16	ASTM D-445

COMBUSTION

NET HEAT OF COMB., BTU/LB
 GROSS HEAT OF COMB., BTU/LB

18039	ASTM D-2382

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
 TDR ΔP

TRACE METAL ANALYSIS, PPM

Al
 As
 Ba
 Ca
 Cd
 Cr, total
 Cu
 Fe, total
 Hg
 K
 Mg
 Mn
 Mo
 Na
 Ni
 Pb
 Se
 Si
 Ti
 V
 Zn

6.3	Emission Spectroscopy
.009	
1.2	
13.	
.3	
.3	
1.1	
.1	
.1	
5.	
ND(2)	
.2	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-5

FUEL
PROPERTIES

FUEL TYPE Syncrude Fraction 400°F+
 FROM REFERENCE A-036 H-Coal

SHEET ___ OF ___

H-COAL PROCESS SYNCRUDES

From Illinois, No. 6, by Mobil Res. and Dev. Corp

General Conclusion: see page 8, "Conclusion"

Identification: see Table B-7

FUEL TYPE H-Coal
FROM REFERENCE A-036

SHEET OF

FUEL PROPERTIES

Conclusions

H-Coal naphtha is high in oxygen and basic nitrogen, due to the presence of phenols, anilines and pyridines. Neither the naphtha nor the fuel oil meets existing gasoline or distillate fuel oil specifications, due in part to relatively high levels of sulfur, nitrogen, and oxygen. Sulfur and nitrogen also interfere with standard refining processes that are used to make gasoline, such as reforming, and would need to be removed by, for example, hydrotreatment. The naphtha contains predominantly cyclic compounds and, upon refining, should yield high octane gasoline and hydrogen, primarily due to dehydrogenation of naphthenes.

Literature Cited

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- (2) C. J. Robinson and G. L. Cook, Anal. Chem. 41, 1548 (1969).
- (3) F. P. Richter, P. D. Caesar, S. L. Meisel, and R. D. Offenbauer, Ind. Eng. Chem. 44, 2601 (1952).
- (4) R. B. Callen, J. G. Bendoraitis, C. A. Simpson, and S. E. Voltz, Ind. Eng. Chem., Prod. Res. Dev. 15, 222-233 (1976).

FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1
TABLE B-6

SPC-6009-ED-02 (12/80)

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Identification and Source of H-Coal Liquids

Product Stream	Atmospheric Still Overhead	Atmospheric Still Bottoms
Source	HRI PDU in Trenton, N. J.	
Operating Mode	Syncrude	
Run Number	PDU Run 5, 130-82-29A	
HRI Sample No.		
30 Gallon	LO-916	LO-917
1 "	LO-918	LO-919
Quantity, Gallon		
Metal Drum	30	30
Glass Bottle	1	1
Coal Source	Illinois No. 6, Burning Star Mine	
Mobil Sample No.		
30 Gallon	77D-3735	77D-3734
1 "	77-94341	77-94342

FUEL TYPE H-Coal
FROM REFERENCE A-036

FUEL
PROPERTIES

FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 60/J9-1

TABLE B-7

SHEET OF

COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL %
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT%
 ON 100%, WT%
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL %
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

86.52	
12.8	
0.33	
0.33	
0.02	
14	
0.23	
<0.01	

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

421/366	D-2887 (2) D86
637/531	
804/684	
924/ND(3)	
1016/ND	
200	
30	

NOTES

- 1) Aromaticity % C_A
 2) ASTM procedure modified by decreasing rate to prevent foaming, 3) 729°F at 84%-sample cracked!

FLUIDITY

POUR POINT, °F
 VISCOSITY, KINEMATIC, cS
 100°F 40°C
 122°F 100°C
 210°F
 VISCOSITY, SAYBOLT UNIV., SEC
 100°F
 122°F
 210°F

TEST METHOD

95	
14.45	
3.15	

COMBUSTION

NET HEAT OF COMB., BTU/LB
 GROSS HEAT OF COMB., BTU/LB

19,365	

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
 TDR ΔP

TRACE METAL ANALYSIS, PPM

Al
 As
 Ba
 Ca
 Cd
 Cr, total
 Cu
 Fe, total
 Hg
 K
 Mg
 Mn
 Mo
 Na
 Ni
 Pb
 Se
 Si
 Ti
 V
 Zn

0.96	
6.7	
2.6	
1.4	
0.36	
<0.01	
<0.1	
0.12	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-8

FUEL
PROPERTIES

FUEL TYPE Shale Oil (Paraho) No. 11
 FROM REFERENCE ASME 80-GT-67

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	84.9			POUR POINT, °F			
HYDROGEN, WT %	11.6			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	3.0			100°F 40°C	.95		
NITROGEN TOTAL, WT %	.3			122°F			
SULFUR TOTAL, WT %	.2			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL-% WT %	10.3			100°F			
OLEFINS, VOL-% WT %	4.9			122°F			
NAPHTHENES, VOL-% WT %	26.4			210°F			
AROMATICS TOTAL, VOL-% WT %	57.0			COMBUSTION			
NAPHTHALENES, VOL-% WT %				NET HEAT OF COMB., BTU/LB	18,597		
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT %				THERMAL STABILITY			
ON 100%, WT %				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	<10.	ASTM D-482		TOR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al	2.3		
WATER, VOL-% WT %	.5			As	.005		
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca	.08		
WAX, MELT TEMPERATURE, °F				Cd	det.		
				Cr, total			
				Cu			
				Fe, total	.4		
				Hg	ND(.02)		
				K	.07		
				Mg	.01		
				Mn			
				Mo			
				Na	.3		
				Ni	.1		
				Pb	.2		
				Se			
				Si	.34		
				Ti	ND(.2)		
				V	.1		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	98	ASTM D-86					
10% EVAPORATED	182						
50% EVAPORATED	322						
90% EVAPORATED	400						
FINAL BOILING POINT	452						
RESIDUE, VOL %							
FLASH POINT, °F	9						
GRAVITY, °API	35						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
det.= detected							
ND= Not detected at detection limit shown							
FUEL QUALITY/PROCESSING STUDY				FUEL TYPE Naphtha			
RMP JOB NO. 6009-1 TABLE B-9				FROM REFERENCE A-036 H-Coal			
				SHEET ____ OF ____			

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COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT % 0.1
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL %
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT% 2.52
 ON 100%, WT%
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL % mg/l 31.6
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT 414
 10% EVAPORATED 472
 50% EVAPORATED 514
 90% EVAPORATED 592
 FINAL BOILING POINT 670
 RESIDUE, VOL %
 FLASH POINT, °F 235
 GRAVITY, °API 13.6
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

ASTM D-1160
 ASTM D-56 (93)
 Digital Density Met.

NOTES

ND=Not Detected at detection limit shown
 1) Values are composite values from the 400-650°F
 and 650°F+ analysis.

FLUIDITY

POUR POINT, °F -45
 VISCOSITY, KINEMATIC, cS
 100°F 4.16
 122°F
 210°F
 VISCOSITY, SAYBOLT UNIV., SEC
 100°F
 122°F
 210°F

TEST METHOD

ASTM D-97

ASTM D-445

COMBUSTION

NET HEAT OF COMB., BTU/LB 18039
 GROSS HEAT OF COMB., BTU/LB

ASTM D-2382

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
 TDR ΔP

TRACE METAL ANALYSIS, PPM

Al 6.3
 As .009
 Ba
 Ca 1.2
 Cd
 Cr, total
 Cu
 Fe, total 13
 Hg
 K .3
 Mg .3
 Mn
 Mo
 Na 1.1
 Ni .1
 Pb .1
 Se
 Si 5
 Ti ND(2)
 V .2
 Zn

Emission Spectroscopy

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-10

FUEL
PROPERTIES

FUEL TYPE Syncrude Fraction 400°F
 FROM REFERENCE A-036 H-Coal

SHEET ____ OF ____

COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL %
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT%
 ON 100%, WT%
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL %
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

88.8	
9.7	
1.0	
0.4	
0.1	
10	ASTM D-482

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

408	ASTM D-2887
443	"
509	"
583	"
657	"
225	
15.1	

NOTES

ND= Not detected at detection limit shown

FLUIDITY

POUR POINT, °F
 VISCOSITY, KINEMATIC, cS
 100°F 40°C
 122°F 100°C
 210°F
 VISCOSITY, SAYBOLT UNIV., SEC
 100°F
 122°F
 210°F

TEST METHOD

-35	
3.369	
1.224	

COMBUSTION

NET HEAT OF COMB., BTU/LB
 GROSS HEAT OF COMB., BTU/LB

18068	

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
 TDR ΔP

TRACE METAL ANALYSIS, PPM

Al
 As
 Ba
 Ca
 Cd
 Cr, total
 Cu
 Fe, total
 Hg
 K
 Mg
 Mn
 Mo
 Na
 Ni
 Pb
 Se
 Si
 Ti
 V
 Zn

1.5	
.005	
1.0	
2.2	
.14	
.03	
.01	
.2	
.1	
.1	
ND(5)	
ND(2)	
.2	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1

TABLE B-11

FUEL
PROPERTIES

FUEL TYPE Distillate 400-650°F
 FROM REFERENCE A-036 H-Coal

SHEET ____ OF ____

COMPOSITION

CARBON, WT %
HYDROGEN, WT %
OXYGEN, WT %
NITROGEN TOTAL, WT %
SULFUR TOTAL, WT %
SULFUR, MERCAPTAN, WT %
PARAFFINS, VOL %
OLEFINS, VOL %
NAPHTHENES, VOL %
AROMATICS TOTAL, VOL %
NAPHTHALENES, VOL %
POLYNUCLEAR AROMATICS, VOL %
CARBON RESIDUE ON 10%, WT %
ON 100%, WT %
ASH, WT %
ASH MELT TEMPERATURE, °F
FILTERABLE DIRT, MG/100 ML
WATER, VOL %
WATER & SEDIMENT, VOL %
WAX, WT %
WAX, MELT TEMPERATURE, °F

VOLATILITY

DISTILLATION TEMP., °F MAX
INITIAL BOILING POINT
10% EVAPORATED
50% EVAPORATED
90% EVAPORATED
FINAL BOILING POINT
RESIDUE, VOL %
FLASH POINT, °F
GRAVITY, °API
GRAVITY, SPECIFIC, 60°F
100°F
210°F

NOTES

ND=Not detected at detection limit shown

TEST METHOD

[illegible]

FLUIDITY

POUR POINT, °F
VISCOSITY, KINEMATIC, cS
400°F 40°C
122°F 100°C
210°F
VISCOSITY, SAYBOLT UNIV., SEC
100°F
122°F
210°F

COMBUSTION

NET HEAT OF COMB., BTU/LB
GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
TDR ΔP

TRACE METAL ANALYSIS, PPM

Al	49
As	.04
Ba	D
Ca	11.
Cd	
Cr, total	D
Cu	D
Fe, total	115.
Hg	ND(0.3)
K	3.
Mg	3.
Mn	D
Mo	
Na	9.
Ni	.3
Pb	.2
Se	
Si	50.
Ti	ND(2)
V	.2
Zn	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-12

FUEL PROPERTIES

FUEL TYPE Residue 650°F+

FROM REFERENCE A-036 H-Coal

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	70.		
HYDROGEN, WT %	11.4			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.013			-100°F 40°C	205.1		
NITROGEN TOTAL, WT %	1.82			122°F 100°C	43.8		
SULFUR TOTAL, WT %	0.84			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL % (1)	5.1			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	18476		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
CON. CARBON ON 100%, WT%	3.6			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	15.0		
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn	1.3		
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	185	Analyzed by Union Oil Co.					
10% EVAPORATED	578						
50% EVAPORATED	865						
90% EVAPORATED	1108						
FINAL BOILING POINT	1113						
RESIDUE, VOL %							
FLASH POINT, °F	155						
GRAVIT., °API	20.2						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
1) Aromaticity % C _A (Carbon NMR used)							

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-13

FUEL
PROPERTIESFUEL TYPE Deashed Shale Oil, No. 12
FROM REFERENCE ASME 80-GT-67

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F		90	
HYDROGEN, WT %	12.2			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	0.004			100°F 40°C	131.5		
NITROGEN TOTAL, WT %	1.63			122°F 100°C	40.4		
SULFUR TOTAL, WT %	0.12			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL % (1)	5.0			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	19011		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
CON. CARBON ON 100%, WT%	0.70			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	3.4		
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn	0.1		
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	165	Analyzed by Union Oil Co.					
10% EVAPORATED	454						
50% EVAPORATED	789						
90% EVAPORATED	995						
FINAL BOILING POINT	1097						
RESIDUE, VOL %							
FLASH POINT, °F	198						
GRAVITY, °API	22.1						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
1) Aromaticity % C _A (Carbon NMR used)							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE Desulfurized Shale Oil, No.13			
RMP JOB NO. 6009-1 TABLE B-14				FROM REFERENCE ASME 80-GT-67			
				SHEET ____ OF ____			

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	<-65		
HYDROGEN, WT %	8.83			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	4.65			100°F 40°C	3.20		
NITROGEN TOTAL, WT %	0.91			122°F 100°C	1.08		
SULFUR TOTAL, WT %	0.21			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL % (1)	63			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	17102		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
CON. CARBON ON 100%, WT%	0.17			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	<0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca	0.52		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	2.1		
				Hg			
				K	2.0		
				Mg			
				Mn			
				Mo			
				Na	5.0		
				Ni			
				Pb	0.29		
				Se	<0.01		
				Si			
				Ti	<0.1		
				V	0.12		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	279/210	D-2887	D-86				
10% EVAPORATED	355/396						
50% EVAPORATED	439/444						
90% EVAPORATED	514/509						
FINAL BOILING POINT	584/546						
RESIDUE, VOL %							
FLASH POINT, °F	169						
GRAVITY, °API	13.3						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
1) Aromaticity % C _A							
FUEL QUALITY/PROCESSING STUDY				FUEL PROPERTIES			
RMP JOB NO. 6009-1 TABLE B-15				FUEL TYPE SRC-II Medium Dist., No. 8			
				FROM REFERENCE ASME 80-GT-67			
				SHEET ____ OF ____			

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	0		
HYDROGEN, WT %	7.13			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	2.04			100°F 40°C	44.54		
NITROGEN TOTAL, WT %	0.98			122°F 100°C	4.06		
SULFUR TOTAL, WT %	0.42			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL % (1)	77			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	17071		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
CON. CARBON ON 100%, WT%	2.15			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.14			TOR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca	25.0		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	155.		
				Hg			
				K	63.0		
				Mg			
				Mn			
				Mo			
				Na	31.0		
				Ni			
				Pb	0.54		
				Se	<0.01		
				Si			
				Ti	7.1		
				V	2.3		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	367/476	D-2887	D-86				
10% EVAPORATED	527/571						
50% EVAPORATED	603/646						
90% EVAPORATED	745/ND(2)						
FINAL BOILING POINT	930/ND						
RESIDUE, VOL %							
FLASH POINT, °F	285						
GRAVITY, °API	0.2						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
1) Aromaticity % C _A							
ND=Not determined							
2) 750°F at 80%							
FUEL QUALITY/PROCESSING STUDY				FUEL			
RMP JOB NO. 6009-1 TABLE B-16				PROPERTIES			
FUEL TYPE SRC-II Heavy Distillate, No. 9				FROM REFERENCE ASME 80-GT-67			
SHEET ____ OF ____							

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COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL % (1)
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT %
 CON. CARBON ON 100%, WT %
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL %
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

7.22	
1.80	
0.94	
0.35	
71	
0.85	
0.03	

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

503/533	D-2887	D-86
545/589		
619/632		
768/ND(2)		
1098/ND		
290		
0.9		

NOTES

- 1) Aromaticity % C_A
 2) 750°F at 36%

NA=Not Determined

FLUIDITY

POUR POINT, °F

0

VISCOSITY, KINEMATIC, cS

100°F 40°C

30.76

122°F 100°C

3.45

210°F

VISCOSITY, SAYBOLT UNIV., SEC

100°F

122°F

210°F

COMBUSTION

NET HEAT OF COMB., BTU/LB

GROSS HEAT OF COMB., BTU/LB

17259

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F

TDR ΔP

TRACE METAL ANALYSIS, PPM

Al

As

Ba

Ca

Cd

Cr, total

Cu

Fe, total

Hg

K

Mg

Mn

Mo

Na

Ni

Pb

Se

Si

Ti

V

Zn

9.1

85.0

7.2

14.0

0.1

0.04

2.7

0.23

TEST METHOD

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1

TABLE B-17

FUEL
PROPERTIES

FUEL TYPE SRC-II, Heavy Dist., No. 9A, 2nd Bat
 FROM REFERENCE ASME 80-GT-67

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	<-65		
HYDROGEN, WT %	8.70			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	4.35			100°F 40°C	3.87		
NITROGEN TOTAL, WT %	0.91			122°F 100°C	1.19		
SULFUR TOTAL, WT %	0.23			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL % (1)	63			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	17090		
CARBON RESIDUE ON 10%, WT %				THERMAL STABILITY			
CON. CARBON ON 100%, WT %	0.36			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	<0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca	1.6		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	13		
				Hg			
				K	1.5		
				Mg			
				Mn			
				Mo			
				Na	1.4		
				Ni			
				Pb	0.12		
				Se	<0.01		
				Si			
				Ti	0.5		
				V	0.23		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	276/220	D-2887	D-86				
10% EVAPORATED	358/404						
50% EVAPORATED	445/459						
90% EVAPORATED	540/578						
FINAL BOILING POINT	762/640						
RESIDUE, VOL %							
FLASH POINT, °F	168						
GRAVITY, °API	11.6						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
1) Aromaticity % C _A							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE SRC-II Blend (Medium) No. 10.			
RMP JOB NO. 60G9-1		TABLE B-18		FROM REFERENCE ASME 80-GT-67			
				SHEET ____ OF ____			

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	86.45			POUR POINT, °F			
HYDROGEN, WT% - ppm	13.59			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT% - ppm	34.			100°F			
NITROGEN TOTAL, WT% = ppm	0.63			122°F			
SULFUR TOTAL, WT% ppm	3.9			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	153.						
10% EVAPORATED	199.						
50% EVAPORATED	263.						
90% EVAPORATED	352.						
FINAL BOILING POINT	393.						
RESIDUE, VOL % RECOVERY	99.						
FLASH POINT, °F							
GRAVITY, °API							
GRAVITY, SPECIFIC, 60°F SPE.	46.8						
100°F	0.7936						
210°F							
NOTES							
Chloride Wt. ppm -	4.0						
Bromine Index	296.						
RON clear	66.8						
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE <u>Upgraded Naphtha Hydrotreated</u>		FROM REFERENCE <u>A-024</u>	
RMP JOB NO. 6009-1 TABLE B-19						SHEET <u> </u> OF <u> </u>	

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COMPOSITION

CARBON, WT %
HYDROGEN, WT %
OXYGEN, WT % ppm
NITROGEN TOTAL, WT % ppm
SULFUR TOTAL, WT % ppm
SULFUR, MERCAPTAN, WT %
PARAFFINS, VOL %
OLEFINS, VOL %
NAPHTHENES, VOL %
AROMATICS TOTAL, VOL %
NAPHTHALENES, VOL %
POLYNUCLEAR AROMATICS, VOL %
CARBON RESIDUE ON 10%, WT %
ON 100%, WT %
ASH, WT %
ASH MELT TEMPERATURE, °F
FILTERABLE DIRT, MG/100 ML
WATER, VOL %
WATER & SEDIMENT, VOL %
WAX, WT %
WAX MELT TEMPERATURE, °F

VOLATILITY

DISTILLATION TEMP., °F MAX
INITIAL BOILING POINT
10% EVAPORATED
50% EVAPORATED
90% EVAPORATED
FINAL BOILING POINT
~~RESIDUE~~ VOL % RECOVERY
FLASH POINT, °F
GRAVITY, °API
GRAVITY, SPECIFIC, 60°F
100°F
210°F

NOTES Chloride, Wt. ppm
Bromine Index
N₂ Jet Gum mg/100ml

TEST METHOD

[illegible]

FLUIDITY

POUR POINT, °F
 VISCOSITY, KINEMATIC, cS
 100°F
 122°F
 210°F
 VISCOSITY, SAYBOLT UNIV., SEC
 100°F
 122°F
 210°F

COMBUSTION

NET HEAT OF COMB., BTU/LB
GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
TDR ΔP

TRACE METAL ANALYSIS, PPM

Al
As
Ba
Ca
Cd
Cr, total
Cu
Fe, total
Hg
K
Mg
Mn
Mo
Na
Ni
Pb
Se
Si
Ti
V
Zn

TEST METHOD

[illegible]

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-20

FUEL PROPERTIES

FUEL TYPE Rerun--Naphtha
FROM REFERENCE A-024

SHEET ____ OF ____

TABLE B-21 - MS Analysis of H-Coal Naphtha 3531-1-2

<u>Hydrocarbon Types</u>	<u>Vol-%</u>
Paraffins	16.2
Naphthenes	
Monocycloparaffins	48.1
Bi, Dicycloparaffins	7.2
Tricycloparaffins	0.2
Aromatics	
Alkylbenzenes	12.7
Indanes/tetralins	5.8
Naphthalenes	0.1
Polars	
Phenols	3.1
Pyridines	0.8
Thiophenes	0.3
Olefins*	
Monoolefins	1.3
Diolefins or Monocycloolefins	3.7
Triolefins or Dicyclomonoolefins	0.5
Total	<u>100.0</u>

<u>Carbon No.</u>	<u>Aromatics</u>			<u>Polars</u>	
	J=6	J=8	J=12	J=6 ⁰	J=5 ^N
5					0.4
6	0.45			0.8	0.2
7	2.84			1.6	0.2
8	4.04	0.10		0.7	
9	2.96	1.67			
10	1.68	3.31	0.1		
11	0.68	0.71			
12	0.03	0.02			
Total	<u>12.68</u>	<u>5.81</u>	<u>0.1</u>	<u>3.1</u>	<u>0.8</u>

* The total olefin number was obtained by SiO₂ separation, but the split is estimated since no calibration coefficients are available.

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	89.70			POUR POINT, °F	70		
HYDROGEN, WT %	7.58			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	2.18			100°F			
NITROGEN TOTAL, WT %	1.46			122°F			
SULFUR TOTAL, WT %	0.55			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, Wt % Heptane Ins	15.2			100°F			
OLEFINS, Wt% Benzene Ins	5.0			210°F-210°	35.25		
NAPHTHENES, VOL %				-250°F-250°	14.08		
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.02	ASTM		TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
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VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	407						
10% EVAPORATED	515						
50% EVAPORATED	760						
90% EVAPORATED	951						
FINAL BOILING POINT	-						
RESIDUE, VOL %	20						
FLASH POINT, °F							
GRAVITY, °API	-3.5						
GRAVITY, SPECIFIC, 60°F	1.1055						
100°F							
210°F							
NOTES							
C1 670 ppm							
FUEL QUALITY/PROCESSING STUDY				FUEL TYPE Synthoil Filtrate			
RMP JOB NO. 6009-1 TABLE B-22				FROM REFERENCE Characteristic of Coal			
				Lignite FE-2010-9			
				SHEET ___ OF ___			

COMPOSITION		TEST METHOD	FLUIDITY		TEST METHOD
CARBON, WT %	-		POUR POINT, °F		
HYDROGEN, WT %	-		VISCOSITY, KINEMATIC, cS		
OXYGEN, WT %	0.5		100°F		
NITROGEN TOTAL, WT %	0.35		122°F		
SULFUR TOTAL, WT %	0.1		210°F		
SULFUR, MERCAPTAN, WT %			VISCOSITY, SAYBOLT UNIV., SEC		
PARAFFINS, VOL %			100°F		
OLEFINS, VOL %			122°F		
NAPHTHENES, VOL %			210°F		
AROMATICS TOTAL, VOL % (FIA)	91.		COMBUSTION		
NAPHTHALENES, VOL %			NET HEAT OF COMB., BTU/LB		
POLYNUCLEAR AROMATICS, VOL %			GROSS HEAT OF COMB., BTU/LB		
CARBON RESIDUE ON 10%, WT%	0.41		THERMAL STABILITY		
ON 100%, WT%			JFTOT, BREAKPOINT TEMP., °F		
ASH, WT %			TDR ΔP		
ASH MELT TEMPERATURE, °F			TRACE METAL ANALYSIS, PPM		
FILTERABLE DIRT, MG/100 ML			Al		
WATER, VOL %			As		
WATER & SEDIMENT, VOL %			Ba		
WAX, WT %			Ca		
WAX, MELT TEMPERATURE, °F			Cd		
			Cr, total		
			Cu		
			Fe, total		
			Hg		
			K		
			Mg		
			Mn		
			Mo		
			Na		
			Ni		
			Pb		
			Se		
			Si		
			Ti		
			V		
			Zn		
VOLATILITY			ORIGINAL PAGE IS OF POOR QUALITY		
DISTILLATION TEMP., °F MAX					
INITIAL BOILING POINT					
10% EVAPORATED					
50% EVAPORATED					
90% EVAPORATED					
FINAL BOILING POINT	857				
RESIDUE, VOL %					
FLASH POINT, °F					
GRAVITY, °API	7.4				
GRAVITY, SPECIFIC, 60°F					
100°F					
210°F					
NOTES					
*as received					
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE <u>H-Coal Process, 400°F+</u>	
RMP JOB NO. 6009-1 TABLE B-23				FROM REFERENCE <u>A-026 *(A)</u>	
				SHEET <u> </u> OF <u> </u>	

COMPOSITION		TEST METHOD	FLUIDITY		TEST METHOD
CARBON, WT %	89.32		POUR POINT, °F		
HYDROGEN, WT %	9.14		VISCOSITY, KINEMATIC, cS		
OXYGEN, WT %	0.52		100°F		
NITROGEN TOTAL, WT %	0.41		122°F		
SULFUR TOTAL, WT %	0.08		210°F		
SULFUR, MERCAPTAN, WT %			VISCOSITY, SAYBOLT UNIV., SEC		
PARAFFINS, VOL %			100°F		
OLEFINS, VOL %			122°F		
NAPHTHENES, VOL %			210°F		
AROMATICS TOTAL, VOL %	90		COMBUSTION		
NAPHTHALENES, VOL %			NET HEAT OF COMB., BTU/LB		
POLYNUCLEAR AROMATICS, VOL %			GROSS HEAT OF COMB., BTU/LB		
CARBON RESIDUE ON 10%, WT%	<0.01		THERMAL STABILITY		
ON 100%, WT%			JFTOT, BREAKPOINT TEMP., °F		
ASH, WT %			TDR ΔP		
ASH MELT TEMPERATURE, °F			TRACE METAL ANALYSIS, PPM		
FILTERABLE DIRT, MG/100 ML			Al		
WATER, VOL %			As		
WATER & SEDIMENT, VOL %			Ba		
WAX, WT %			Ca		
WAX, MELT TEMPERATURE, °F			Cd		
			Cr, total		
			Cu		
			Fe, total		
			Hg		
			K		
			Mg		
			Mn		
			Mo		
			Na		
			Ni		
			Pb		
			Se		
			Si		
			Ti		
			V		
			Zn		
VOLATILITY			ORIGINAL PAGE IS OF POOR QUALITY		
DISTILLATION TEMP., °F MAX					
INITIAL BOILING POINT					
10% EVAPORATED					
50% EVAPORATED					
90% EVAPORATED					
FINAL BOILING POINT	769				
RESIDUE, VOL %					
FLASH POINT, °F					
GRAVITY, °API	8.9				
GRAVITY, SPECIFIC, 60°F					
100°F					
210°F					
NOTES					
*Rerun, 94 VOL. % Overhead					
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE <u>H-Coal Process, 400°F+</u>	
RMP JOB NO. 6009-1 TABLE B-24				FROM REFERENCE <u>A-026 * (B)</u>	
				SHEET ____ OF ____	

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H-COAL PROCESS DERIVED LIQUIDS

Feed for upgrading investigation to evaluate the applicability of commercial UOP hydrotreating and reforming process.

Coal feed is not known. Clearness did not last.

--Naphthas:

The primary H-Coal naphtha was rerun in a laboratory column to remove color materials and heavy ends generated during storage.

Naphtha feed for Platformer was mixed and blended respectively with earlier derived Naphthas from H-Coal process.

--400°F+ Distillates

Hydrotreatment is required prior to either hydrocracking or FCC to reduce excessive amounts of nitrogen and to enhance processability.

Hydrotreating alone will give high yields of environmentally acceptable No. 2 fuel oils.

5. CONCLUSIONS

These studies show that hydrotreating, hydrocracking, fluid catalytic cracking and reforming are applicable to coal-derived distillates. In general the liquids will require hydrogen pretreatment before cracking or reforming to reduce excessive amounts of nitrogen, to enhance processability, and to make the products more environmentally acceptable. Hydrogen is consumed to partially saturate polynuclear aromatics. This renders the stock more susceptible to cracking, and less prone to form coke on catalysts.

The advanced commercial catalysts employed for petroleum conversion are suitable for refining coal derived distillates to premium value products. Process conditions required are within commercially practicable ranges. Hydrogen requirements can be partially met by reforming naphthas and steam reforming light gases.

FUEL TYPE
FROM REFERENCE

A-036

SHEET
OF

FUEL
PROPERTIES

FUEL QUALITY/PROCESSING STUDY

TABLE B-25

RMP JOB NO. 6009-1

H-COAL PROCESS, BENCH SCALE LIQUIEFACATION TESTS

By Hydrocarbon Research, Inc.

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with 2 Kentucky No. 11 Coals

-run-of-mine coal with 17.49 Wt.% ash

-deep-cleaned coal with 6.21 Wt.% ash

from PETC

CONCLUSIONS

- * The deep-cleaned Kentucky No.11 coal exhibited greater coal conversion than the run-of-mine coal. Deep cleaning may remove a fraction of the unreactive m.a.f. coal present in the run-of-mine coal.
- * The deep-cleaned coal yielded more residual oil than the run-of-mine coal. Also, the fraction of residual oil which was toluene-soluble was less for the deep-cleaned coal than for the run-of-mine coal. The high ash level of the run-of-mine coal may increase the conversion of residual oil.
- * There was no marked difference between the two coals in the rates of catalyst deactivation for conversion of toluene-soluble and toluene-insoluble residuum.
- * The total C₄ to 975°F distillate yield on a converted coal basis was about the same for both coals: on a dry coal basis, the deep-cleaned coal yielded approximately 19% more C₄ to 975°F distillate than the run-of-mine coal.
- * In a 25,000 ton per day H-Coal plant operating in the syncrude mode at a catalyst age of 300 lbs coal/lb catalyst, the deep-cleaned coal would yield approximately 10% more C₄ to 975°F product than the run-of-mine coal.
- * On a converted coal basis, the yields of H₂S, NH₃, and H₂O were higher for the run-of-mine coal than for the deep-cleaned coal.
- * The hydrogen consumption on a converted coal basis was higher for the run-of-mine coal than for the deep-cleaned coal.

FUEL TYPE
FROM REFERENCE

A-027

SHEET
OF

FUEL PROPERTIES

FUEL QUALITY/PROCESSING STUDY

TABLE B-26

RMP JOB NO. 6009-1

SPC 6009-ED-02 (2/80)

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SUMMARY OF OPERATING RESULTS

Run Number	177-143	177-144
Kentucky No. 11 Coal	Deep-Cleaned	Run-of-Mine
HRI Number	4018	4017
Ash in Feed Coal, W % (Dry Coal)	6.21	17.49
Catalyst Age, Lbs Coal/Lb Catalyst	31.8-317.8	55.1-327.1
Coal Feed Rate, Lbs/Hr/Ft ₃ Reactor	30.7	31.2
Reactor Temperature, °F	850	850
Pressure, psig	2243	2252
Recycle, Lbs/Lb Coal		
Vacuum Distillate	0.30	0.29
Filtered Liquid	0.69	0.69
Separator Bottoms	4.09	4.13
Coal Conversion, W % M.A.F. Coal	95.90	92.19

Normalized Yields	W % Dry Coal	W % MAF Coal	W % Converted Coal	W % Dry Coal	W % MAF Coal	W % Converted Coal
C ₁ -C ₃ Gases	12.01	12.81	13.36	10.23	12.40	13.45
C ₄ -400°F Naphtha	26.95	28.73	29.96	22.89	27.74	30.09
400-650°F Distillate	18.67	19.91	20.76	17.39	21.08	22.86
650-975°F Distillate	6.37	6.79	7.08	3.35	4.06	4.40
975°F+ Distillate						
Total	17.85	19.03	19.84	11.10	13.45	14.59
Toluene-Soluble	13.88	14.80	15.43	9.43	11.43	12.40
Toluene-Insoluble	3.97	4.23	4.41	1.67	2.02	2.20
Unconverted Coal	3.95	4.21		6.67	8.08	
Ash	6.35			18.11		
H ₂ O (Net)	9.64	10.28	10.72	9.70	11.76	12.75
CO + CO ₂	0.63	0.67	0.70	0.57	0.69	0.75
H ₂ S	2.72	2.90	3.02	3.97	4.81	5.22
NH ₃	1.23	1.31	1.37	1.95	2.36	2.56
Total (100 + H ₂ Reacted)	106.39			105.94		
C ₄ -975°F Distillate						
Barrels/Ton Dry Coal		3.64			3.06	
Barrels/Ton M.A.F. Coal		3.88			3.71	
Barrels/Ton Converted Coal		4.05			4.02	
Sulfur in 975°F+ Oil, W %		0.50			0.45	
Toluene-Soluble in 975°F+, W %		77.76			84.95	
Hydrogen Consumption,						
MSCF/Ton Feed Coal		23.21			21.56	
MSCF/Ton MAF Coal		24.75			26.17	
MSCF/Ton Converted Coal		26.71			29.33	

FUEL TYPE
FROM REFERENCE

FUEL
PROPERTIES

FUEL QUALITY/PROCESSING STUDY
RMP JOB NO. 6009-1
TABLE B-27

SHEET OF

TABLE B-28 - Feed Coal Analyses

Run Number	177-143	177-144
Kentucky No.11 Coal Feed	Deep-Cleaned	Run-Of-Mine
HRI Number	4018	4017
Grind Description	-70 Mesh	-70 Mesh
Moisture, W %	3.14	3.30
Hours of Run	0-192	0-180
Proximate, Dry Basis, W %		
Ash	6.42	18.02
Volatile Matter	39.56	
Fixed Carbon	54.02	
Ultimate, Dry Basis, W %		
Carbon	74.27	63.29
Hydrogen	4.91	3.99
Nitrogen	1.55	1.93
Sulfur	3.70	6.30
Ash	6.42	18.02
Chlorine*	0.07	0.02
Oxygen (Difference)	9.08	6.45
Sulfur Forms, W % (Dry)*		
Pyritic	1.00	3.46
Sulfate	0.24	0.55
Organic	2.07	1.88
Total	3.31	5.89
Mineral, W % Ignited Basis*		
Phosphorous Pentoxide, P_2O_5	0.29	0.26
Silica SiO_2	38.80	37.68
Ferric Oxide Fe_2O_3	31.65	33.41
Alumina Al_2O_3	22.50	20.59
Titania TiO_2	1.07	0.89
Lime CaO	1.52	1.42
Magnesia MgO	0.80	0.45
Sulfur Trioxide SO_3	0.83	0.92
Potassium Oxide K_2O	2.05	1.71
Sodium Oxide Na_2O	0.28	0.29
Barium Oxide BaO	0.09	0.13
Strontium Oxide SrO	0.00	0.00
Manganese Oxide Mn_3O_4	0.06	0.05
Undetermined	0.06	2.20
Heating Value, Btu/Lb	13,020	11,148

* Analyses performed by Commercial Testing and Engineering Company,
Chicago, Illinois

TABLE B-29 - Typical Catalyst Analysis - American Cyanamid HDS-1442A

HRI Number	3830
Bulk Density, gm/cc, Compacted	0.580
Particle Density, gms/cc	
In Mercury	0.983
In Heptane	0.908
From Weight Dimensions	0.917
Skeletal Density, gms/cc	
In Mercury, 60,000 psi	2.93
In Heptane	3.57
Heptane Wetted Density, gms/cc	1.445
Heptane Absorbed, cc/gm	0.821
Average Particle Weight, Milligram	9.20
Particle Length	
Average, mm	4.69
Range, mm	2.4-12.0
Particle Diameter, Average, mm	1.65
Chemical Analysis by Supplier	
MoO ₃ , W %	16.0
Co, W %	3.2
Na ₂ O, W %	0.02
Analysis by HRI	
Molybdenum, W %	9.73
Cobalt, W %	2.75
Iron, W %	0.3
Titanium, W %	0.0
Crush Strength, Lb/mm	3.2
Attrition Test, % Undersize	3.9
Pore Volume (Hg @ 60,000 psi)	
D > 30 Å, cc/gm	0.691
Pore Size Distribution, cc/gm	
D = 30-50 Å	0.142
D = 50-100 Å	0.259
D = 100-200 Å	0.036
D = 200-2000 Å	0.120
D = > 2000 Å	0.134
Maximum, Å*	55

* Position of Greatest Slope of Pore Volume Against Diameter

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	88.53			POUR POINT, °F			
HYDROGEN, WT %	8.93			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F			
NITROGEN TOTAL, WT %	0.62			122°F			
SULFUR TOTAL, WT %	<0.03			210°F 130°F	41		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %				JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TDR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al			
WATER & SEDIMENT, VOL %				As			
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca			
				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY				ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	334						
10% EVAPORATED	421						
50% EVAPORATED	566						
90% EVAPORATED	808						
FINAL BOILING POINT	913						
RESIDUE, wt % Wt. %	3.5						
FLASH POINT, °F							
GRAVITY, °API	10.1						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
Wt. % of DRY COAL	35.22						

FUEL QUALITY/PROCESSING STUDY RMP JOB NO. 6009-1 TABLE B-30	FUEL PROPERTIES	FUEL TYPE <u>Vacuum Distillate</u> FROM REFERENCE <u>A-027</u> SHEET ____ OF ____
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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	87.21			POUR POINT, °F			
HYDROGEN, WT %	11.64			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F	29		
NITROGEN TOTAL, WT %	0.25			122°F			
SULFUR TOTAL, WT %	<0.03			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	164						
10% EVAPORATED	233						
50% EVAPORATED	382						
90% EVAPORATED	515						
FINAL BOILING POINT	630						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	32.6						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
Wt.% of DRY COAL	14.33						

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COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	88.94			POUR POINT, °F			
HYDROGEN, WT %	7.83			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F			
NITROGEN TOTAL, WT %	.93			122°F			
SULFUR TOTAL, WT %	.15			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F	53		
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %				JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TDR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al			
WATER & SEDIMENT, VOL %				As			
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca			
				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	402						
10% EVAPORATED	475						
50% EVAPORATED	702						
90% EVAPORATED	-						
FINAL BOILING POINT	975						
RESIDUE, 10% % Wt.	27.7						
FLASH POINT, °F							
GRAVITY, °API	1.2						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
Wt.% of DRY COAL	5.29						

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-32

**FUEL
PROPERTIES**

FUEL TYPE Filtered Liquid of Vac. Dist.

FROM REFERENCE A-027

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	88.66			POUR POINT, °F			
HYDROGEN, WT %	9.09			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F			
NITROGEN TOTAL, WT %	0.36			122°F			
SULFUR TOTAL, WT %	<0.03			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F 130°F	38		
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY				ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	321.						
10% EVAPORATED	418.						
50% EVAPORATED	539.						
90% EVAPORATED	820.						
FINAL BOILING POINT	925.						
RESIDUE, VOL % Wt. %	2.6						
FLASH POINT, °F							
GRAVITY, °API	11.4						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							

FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1

TABLE B-34

FUEL
PROPERTIESFUEL TYPE Vacuum Distillate
FROM REFERENCE A-027

SHEET ___ OF ___

COMPOSITION

CARBON, WT %
HYDROGEN, WT %
OXYGEN, WT %
NITROGEN TOTAL, WT %
SULFUR TOTAL, WT %
SULFUR, MERCAPTAN, WT %
PARAFFINS, VOL %
OLEFINS, VOL %
NAPHTHENES, VOL %
AROMATICS TOTAL, VOL %
NAPHTHALENES, VOL %
POLYNUCLEAR AROMATICS, VOL %
CARBON RESIDUE ON 10%, WT %
ON 100%, WT %
ASH, WT %
ASH MELT TEMPERATURE, °F
FILTERABLE DIRT, MG/100 ML
WATER, VOL %
WATER & SEDIMENT, VOL %
WAX, WT %
WAX, MELT TEMPERATURE, °F

VOLATILITY

DISTILLATION TEMP., °F MAX
INITIAL BOILING POINT
10% EVAPORATED
50% EVAPORATED
90% EVAPORATED
FINAL BOILING POINT
RESIDUE, ~~Wt.~~ % Wt. %
FLASH POINT, °F
GRAVITY, °API
GRAVITY, SPECIFIC, 60°F
100°F
210°F

NOTES

TEST METHOD

[illegible]

FLUIDITY

POUR POINT, °F
VISCOSITY, KINEMATIC, cS
100°F
122°F
210°F
VISCOSITY, SAYBOLT UNIV., SEC
100°F
122°F
210°F

COMBUSTION

NET HEAT OF COMB., BTU/LB
GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
TDR ΔP

TRACE METAL ANALYSIS, PPM

Al
As
Ba
Ca
Cd
Cr, total
Cu
Fe, total
Hg
K
Mg
Mn
Mo
Na
Ni
Pb
Se
Si
Ti
V
Zn

TEST METHOD

[illegible]

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1

TABLE B-35

FUEL PROPERTIES

FUEL TYPE Filtered Liquids of Vac. Dist
FROM REFERENCE _____

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	5.		
HYDROGEN, WT %	9.27			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	1.79			100°F 40°C	7.13		
NITROGEN TOTAL, WT %	0.61			122°F 100°C	1.78		
SULFUR TOTAL, WT %	0.14			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL % (1)	57			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	17662		
CARBON RESIDUE ON 10%, WT %				THERMAL STABILITY			
CON. CARB. ON 100%, WT %	0.52			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca	0.36		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	58.		
				Hg			
				K	1.5		
				Mg			
				Mn			
				Mo			
				Na	1.90		
				Ni			
				Pb			
				Se	0.42		
				Si	0.01		
				Ti			
				V	<0.01		
				Zn	0.12		
VOLATILITY				ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	305/386	D-2887	D-86				
10% EVAPORATED	397/439						
50% EVAPORATED	537/559						
90% EVAPORATED	703/734						
FINAL BOILING POINT	929/746						
RESIDUE, VOL %							
FLASH POINT, °F	203						
GRAVITY, °API	9.8						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
(1) Aromaticity % C _A							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE H-Coal, Atmosph. Bottoms, No. 4			
RMP JOB NO. 6009-1				FROM REFERENCE ASME 80-GT-67			
TABLE B-36				SHEET ____ OF ____			

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	88.2			POUR POINT, °F	115		
HYDROGEN, WT %	7.36			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	2.65			200 400 °F	465		
NITROGEN TOTAL, WT %	1.3			300 420 °F	22.5		
SULFUR TOTAL, WT %	0.48			400 210 °F	5.0		
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100 °F			
OLEFINS, VOL %				122 °F			
NAPHTHENES, VOL %				210 °F			
AROMATICS TOTAL, VOL %							
NAPHTHALENES, VOL %							
POLYNUCLEAR AROMATICS, VOL %							
Con. CARBON RESIDUE ON 10%, WT%	32.8			COMBUSTION			
ON 100%, WT%				NET HEAT OF COMB., BTU/LB	16700		
ASH, WT %	0.2			GROSS HEAT OF COMB., BTU/LB			
ASH MELT TEMPERATURE, °F							
FILTERABLE DIRT, MG/100 ML				THERMAL STABILITY			
WATER, VOL %	none			FFTF, BREAKPOINT TEMP., °F	200		
WATER & SEDIMENT, VOL %				FFR = ΔP unstable above			
WAX, WT %				TRACE METAL ANALYSIS, PPM			
WAX, MELT TEMPERATURE, °F				Al			
				As			
				Ba			
				Ca	1.5		
				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K	1.7		
				Mg	1.8		
				Mn			
				Mo			
				Na	3.1		
				Ni			
				Pb	0.04		
				Se			
				Si			
				Ti			
				V	2.		
				Zn			
VOLATILITY				<div style="writing-mode: vertical-rl; transform: rotate(180deg);"> ORIGINAL PAGE IS OF POOR QUALITY </div>			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	400						
10% EVAPORATED							
50% EVAPORATED							
90% EVAPORATED							
FINAL BOILING POINT							
RESIDUE, VOL %							
FLASH POINT, °F	350						
GRAVITY, °API	-7.5						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							
FUEL QUALITY/PROCESSING STUDY				FUEL PROPERTIES			
RMP JOB NO. 6009-1 TABLE B-37				FUEL TYPE <u>H-Coal, Hydroclone Bottoms</u> FROM REFERENCE <u>A-041, Table 6,d</u>			
				SHEET ____ OF ____			

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F			
HYDROGEN, WT %				VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F			
NITROGEN TOTAL, WT %	0.18			122°F			
SULFUR TOTAL, WT %	0.0371			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	1.0		
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni	0.2		
				Pb			
				Se			
				Si			
				Ti			
				V	0.2		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	452						
10% EVAPORATED	452						
50% EVAPORATED	514						
90% EVAPORATED	616						
FINAL BOILING POINT	636						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	16.7						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1

TABLE B-38

FUEL
PROPERTIESFUEL TYPE Middle Distillate, H-Coal, II
FROM REFERENCE A-041 - Table 6a(No. 6)

SHEET ___ OF ___

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F			
HYDROGEN, WT %				VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %				100°F			
NITROGEN TOTAL, WT %	0.36			122°F			
SULFUR TOTAL, WT %	0.15			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT% ON 100%, WT%				THERMAL STABILITY			
ASH, WT %				JFTOT, BREAKPOINT TEMP., °F			
ASH MELT TEMPERATURE, °F				TDR ΔP			
FILTERABLE DIRT, MG/100 ML				TRACE METAL ANALYSIS, PPM			
WATER, VOL %				Al			
WATER & SEDIMENT, VOL %				As			
WAX, WT %				Ba			
WAX, MELT TEMPERATURE, °F				Ca			
				Cd			
				Cr, total			
				Cu			
				Fe, total	15.3		
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni	0.2		
				Pb			
				Se			
				Si			
				Ti			
				V	0.2		
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT							
10% EVAPORATED	688						
50% EVAPORATED	737						
90% EVAPORATED	896						
FINAL BOILING POINT							
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	5.4						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1

TABLE B-39

FUEL
PROPERTIESFUEL TYPE Heavy Dist., H-Coal, III. No. 6
FROM REFERENCE A-041 - Table 6-a

SHEET ____ OF ____

COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL %
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT%
 ON 100%, WT%
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL %
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

0.131	
0.18	
70.3	
1.1	
28.6	

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

196	
228	
312	
380	
40.6	

NOTES

FLUIDITY

POUR POINT, °F
 VISCOSITY, KINEMATIC, cS
 100°F
 122°F
 210°F
 VISCOSITY, SAYBOLT UNIV., SEC
 100°F
 122°F
 210°F

TEST METHOD

COMBUSTION

NET HEAT OF COMB., BTU/LB
 GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
 TOR ΔP

--	--

TRACE METAL ANALYSIS, PPM

Al
 As
 Ba
 Ca
 Cd
 Cr, total
 Cu
 Fe, total
 Hg
 K
 Mg
 Mn
 Mo
 Na
 Ni
 Pb
 Se
 Si
 Ti
 V
 Zn

0.5	
0.2	
0.2	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE 3-40

FUEL
PROPERTIES

FUEL TYPE- Naphtha, H-Coal, Ill. No. 6
 FROM REFERENCE A-041, Table 6-a

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	87.6			POUR POINT, °F			
HYDROGEN, WT %	7.4			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	1.93			100°F			
NITROGEN TOTAL, WT %	0.81			122°F			
SULFUR TOTAL, WT %	0.47			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %				TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY				ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	180						
10% EVAPORATED							
50% EVAPORATED							
90% EVAPORATED							
FINAL BOILING POINT	>944						
RESIDUE, VOL %							
FLASH POINT, °F							
GRAVITY, °API	27.6						
GRAVITY, SPECIFIC, 60°F							
100°F							
210°F							
NOTES							

FUEL QUALITY/PROCESSING STUDY	FUEL PROPERTIES	FUEL TYPE <u>H-Coal from Ill. No. 6 full</u>
RMP JOB NO. 6009-1	TABLE B-41	FROM REFERENCE <u>A-041</u> range liq.
		Table 6-a (Ref. #1, ACS)
		SHEET ___ OF ___

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %	79.35			Softening POINT, °F	172		
HYDROGEN, WT %	6.35			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	3.92			100°F			
NITROGEN TOTAL, WT %	1.11			122°F			
SULFUR TOTAL, WT %	1.43			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL % Heptane Ins	49.9			100°F			
OLEFINS, VOL % Benzene Ins	35.0			122°F			
NAPHTHENES, VOL % DMF/Xylene	15.1			210°F 250°F	307.3		
AROMATICS TOTAL, VOL %				COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB			
CON CARBON RESIDUE ON 10%, WT%	39.43			THERMAL STABILITY			
ON 100%, WT%				JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %		ASTM		TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, WT %				Ca			
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total			
				Hg			
				K			
				Mg			
				Mn			
				Mo			
				Na			
				Ni			
				Pb			
				Se			
				Si			
				Ti			
				V			
				Zn			
VOLATILITY							
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	466	ASTM D-1160					
10% EVAPORATED	560						
50% EVAPORATED	876						
90% EVAPORATED	-						
FINAL BOILING POINT							
RESIDUE, VOL %	50						
FLASH POINT, °F							
GRAVITY, °API	-16.5						
GRAVITY, SPECIFIC, 60°F	1.2307						
100°F							
210°F							
NOTES							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE H-Coal Hydroclone Underflow			
RMP JOB NO. 6009-1		TABLE B-42		FROM REFERENCE FE-2010-9			
				SHEET ____ OF ____			

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COMPOSITION

CARBON, WT %	87.07
HYDROGEN, WT %	6.96
OXYGEN, WT %	4.38
NITROGEN TOTAL, WT %	1.30
SULFUR TOTAL, WT %	0.66
SULFUR, MERCAPTAN, WT %	
PARAFFINS, VOL % Heptane Ins	49.0
OLEFINS, VOL % Benzene Ins	29.0
NAPHTHENES, VOL % DMF Xylene	0.03
AROMATICS TOTAL, VOL %	
NAPHTHALENES, VOL %	
POLYNUCLEAR AROMATICS, VOL %	
Con CARBON RESIDUE ON 10%, WT% ON 100%, WT%	33.20
ASH, WT %	0.12
ASH MELT TEMPERATURE, °F	
FILTERABLE DIRT, MG/100 ML	
WATER, VOL %	
WATER & SEDIMENT, VOL %	
WAX, WT %	
WAX, MELT TEMPERATURE, °F	

TEST METHOD

VOLATILITY

DISTILLATION TEMP., °F MAX	
INITIAL BOILING POINT	493
10% EVAPORATED	567
50% EVAPORATED	822
90% EVAPORATED	910
FINAL BOILING POINT	
RESIDUE, VOL %	40
FLASH POINT, °F	
GRAVITY, °API	-17.7
GRAVITY, SPECIFIC, 60°F	1.2433
100°F	
210°F	

ASTM D-1160

NOTES

FLUIDITY

POUR POINT, °F	240
VISCOSITY, KINEMATIC, cS	
100°F	
122°F	
210°F	
VISCOSITY, SAYBOLT UNIV., SEC	
100°F	
122°F 250°F	161.4
210°F 300°F	154.1

TEST METHOD

COMBUSTION

NET HEAT OF COMB., BTU/LB	
GROSS HEAT OF COMB., BTU/LB	

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F	
TDR ΔP	

TRACE METAL ANALYSIS, PPM

Al	
As	
Ba	
Ca	
Cd	
Cr, total	
Cu	
Fe, total	
Hg	
K	
Mg	
Mn	
Mo	
Na	
Ni	
Pb	
Se	
Si	
Ti	
V	
Zn	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-43

FUEL
PROPERTIESFUEL TYPE H-Coal Hydroclone Underflow
FROM REFERENCE Filtrate
FE-2010-9

SHEET ____ OF ____

COMPOSITION		TEST METHOD		FLUIDITY		TEST METHOD	
CARBON, WT %				POUR POINT, °F	<-65.		
HYDROGEN, WT %	11.19			VISCOSITY, KINEMATIC, cS			
OXYGEN, WT %	1.1			100°F 40°C	1.17		
NITROGEN TOTAL, WT %	0.16			122°F 100°C	0.60		
SULFUR TOTAL, WT %	0.16			210°F			
SULFUR, MERCAPTAN, WT %				VISCOSITY, SAYBOLT UNIV., SEC			
PARAFFINS, VOL %				100°F			
OLEFINS, VOL %				122°F			
NAPHTHENES, VOL %				210°F			
AROMATICS TOTAL, VOL % (1)	29			COMBUSTION			
NAPHTHALENES, VOL %				NET HEAT OF COMB., BTU/LB			
POLYNUCLEAR AROMATICS, VOL %				GROSS HEAT OF COMB., BTU/LB	18810		
CARBON RESIDUE ON 10%, WT%				THERMAL STABILITY			
CON. CARB. ON 100%, WT%	0.01			JFTOT, BREAKPOINT TEMP., °F			
ASH, WT %	<0.01			TDR ΔP			
ASH MELT TEMPERATURE, °F				TRACE METAL ANALYSIS, PPM			
FILTERABLE DIRT, MG/100 ML				Al			
WATER, VOL %				As			
WATER & SEDIMENT, VOL %				Ba			
WAX, Wt %				Ca	0.16		
WAX, MELT TEMPERATURE, °F				Cd			
				Cr, total			
				Cu			
				Fe, total	0.7		
				Hg			
				K	0.15		
				Mg			
				Mn			
				Mo			
				Na	1.1		
				Ni			
				Pb	0.02		
				Se	0.01		
				Si			
				Ti	<2.0		
				V	0.1		
				Zn			
VOLATILITY				ORIGINAL PAGE IS OF POOR QUALITY			
DISTILLATION TEMP., °F MAX							
INITIAL BOILING POINT	179/220	D-2887	D-86				
10% EVAPORATED	247/280						
50% EVAPORATED	376/368						
90% EVAPORATED	457/440						
FINAL BOILING POINT	537/485						
RESIDUE, VOL %							
FLASH POINT, °F	12						
GRAVITY, °API	30.4						
GRAVITY, SPECIFIC, 60°F							
	100°F						
	210°F						
NOTES (1) Aromaticity % C _A							
FUEL QUALITY/PROCESSING STUDY		FUEL PROPERTIES		FUEL TYPE <u>H-Coal</u> , 200-500°F Dist. No. 2A			
RMP JOB NO. 6009-1 TABLE B-44				FROM REFERENCE <u>ASME 80-CT-67</u>			
				SHEET ____ OF ____			

COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL % (1)
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT %
 CON. CARB. ON 100%, WT %
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL %
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

11.38	
1.4	
0.16	
0.13	
34	
0.05	
<0.01	

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

176/236	
257/304	
369/374	
447/442	
550/505	
<75.	
30.	

NOTES (1) Aromaticity % C_A

FLUIDITY

POUR POINT, °F
 VISCOSITY, KINEMATIC, cS
 100°F
 122°F
 210°F
 VISCOSITY, SAYBOLT UNIV., SEC
 100°F 40°C
 122°F 100°C
 210°F

TEST METHOD

<-65.	
1.12	
.62	

COMBUSTION

NET HEAT OF COMB., BTU/LB
 GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
 TDR ΔP

TRACE METAL ANALYSIS, PPM

Al
 As
 Ba
 Ca
 Cd
 Cr, total
 Cu
 Fe, total
 Hg
 K
 Mg
 Mn
 Mo
 Na
 Ni
 Pb
 Se
 Si
 Ti
 V
 Zn

0.15	
0.7	
0.06	
0.43	
0.02	
<0.2	
<1.0	
0.9	

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-45

FUEL
PROPERTIES

FUEL TYPE H-Coal, 200-500°F Dist. No. 2
 FROM REFERENCE ASME 80-GT-67

SHEET ____ OF ____

COMPOSITION

CARBON, WT %
 HYDROGEN, WT %
 OXYGEN, WT %
 NITROGEN TOTAL, WT %
 SULFUR TOTAL, WT %
 SULFUR, MERCAPTAN, WT %
 PARAFFINS, VOL %
 OLEFINS, VOL %
 NAPHTHENES, VOL %
 AROMATICS TOTAL, VOL % (1)
 NAPHTHALENES, VOL %
 POLYNUCLEAR AROMATICS, VOL %
 CARBON RESIDUE ON 10%, WT %
 Con. Carb. ~~ON 100%~~ WT %
 ASH, WT %
 ASH MELT TEMPERATURE, °F
 FILTERABLE DIRT, MG/100 ML
 WATER, VOL %
 WATER & SEDIMENT, VOL %
 WAX, WT %
 WAX, MELT TEMPERATURE, °F

TEST METHOD

10.03	
1.2	
0.33	
0.09	
43.	
0.08	
<0.01	

VOLATILITY

DISTILLATION TEMP., °F MAX
 INITIAL BOILING POINT
 10% EVAPORATED
 50% EVAPORATED
 90% EVAPORATED
 FINAL BOILING POINT
 RESIDUE, VOL %
 FLASH POINT, °F
 GRAVITY, °API
 GRAVITY, SPECIFIC, 60°F
 100°F
 210°F

295/352	D-2887	D-86
389/418		
458/458		
558/576		
685/634		
145.		
18.4		

NOTES

(1) Aromaticity % C_A

FLUIDITY

POUR POINT, °F
 VISCOSITY, KINEMATIC, cS
 100°F 40°C
 122°F 100°C
 210°F

VISCOSITY, SAYBOLT UNIV., SEC

100°F
 122°F
 210°F

COMBUSTION

NET HEAT OF COMB., BTU/LB
 GROSS HEAT OF COMB., BTU/LB

THERMAL STABILITY

JFTOT, BREAKPOINT TEMP., °F
 TDR ΔP

TRACE METAL ANALYSIS, PPM

Al
 As
 Ba
 Ca
 Cd
 Cr, total
 Cu
 Fe, total
 Hg
 K
 Mg
 Mn
 Mo
 Na
 Ni
 Pb
 Se
 Si
 Ti
 V
 Zn

TEST METHOD

<-65.

2.56

0.89

18331

0.29

3.7

0.26

0.67

0.14-

<0.1

<0.1

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FUEL QUALITY/PROCESSING STUDY

RMP JOB NO. 6009-1 TABLE B-46

FUEL
PROPERTIES

FUEL TYPE H-Coal 400-650°F Dist. No. 3
 FROM REFERENCE ASME 80-GT-67

SHEET ____ OF ____

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The analyses sheets in the balance of Appendix B are for H-Coal, SRC and EDS liquification process liquid fuels. These are from an earlier study by NASA-Lewis: Reynolds, T. W., R. W. Niedz-wiecki and J. S. Clark, "LITERATURE SURVEY OF PROPERTIES OF SYN-FUELS DERIVED FROM COAL", prepared for DOE Report No. DOE/NASA/2593-79/8, NASA TM-79243.

These are presented as pertinent information predating the Fuel Quality/Processing Study, Task I.

TABLE 4. - FUEL DATA FROM D-COAL PROCESS

(a) D-Coal from Illinois 60 coal (fuel oil mode); data from ref. 1

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Property	Test	Distillate categories					
		Full-range liquid	Residue	Middle distillate	Heavy distillate		
Gravity, °API (specific)		27.6	48.6	36.7	3.4		
Boiling range:							
Initial boiling point, °F		300	306	457			
1 %			215	452	687		
10 %			229	457	688		
30 %			250	454	699		
50 %			276	470	708		
60 %			282	482	722		
70 %			292	514	727		
80 %			332	534	736		
90 %			250	270	783		
95 %			266	292	867		
99 %			280	414	886		
99.5 %			294	427	864		
Final boiling point, °F		944		624			
Pour point, °F							
Flashpoint, °F							
Viscosity at							
at							
at							
Ash, wt %							
Ash melt temperature, °F							
Heat of combustion, Btu/lb							
Carbon residue							
Carbon remainder, wt %							
Thermal stability							
Electrical conductivity							
Water							
Acidic							
Neutral							
Corrosive							
Hydrotreatment type:							
Bromine			70.3				
Olefins			1.1				
Aromatics, total			25.6				
Aromatics, polynuclear							
Luminometer number							
Analysis point, °F							
H/C mole ratio							
Elemental analysis, wt %:							
C		87.6					
H		7.6					
N		0.81	0.33	0.18	0.36		
S		0.47	0.18	0.037	0.15		
O		1.92					
Trace metal analysis, ppm:							
V			0.2	0.2	0.2		
Ni			0.2	0.2	0.2		
Na							
K							
Mg							
Ca							
Pb							
Co							
Fe			0.5	1.0	15.2		
B							
Zn							
Mn							
Mo							
W							
Cu							

(b) D-Coal liquids; data from Letter of Feb. 16, 1977, to Lloyd L. Shure, Santa Louis Research Center, from C. S. Pm, General Electric Research and Development Center

ORIGINAL PAGE 19
OF POOR QUALITY

B-50

TABLE 4. - Continued

(c) D-Oil from Illinois 66 well; data from ref. 3

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Property	Test	Distillate composition							
		Headline (100° - 350°F; 19.8 wt%)	Middle distillate (350° - 550°F; 32.3 wt%)	Vac. gas oil (450° - 800°F; 21.5 wt%)	Residue (800°F+; 26.6 wt%)				
Gravity, °API (specific)		64.9	25.9	7.9					
Boiling range:									
Initial boiling point, °F		-50	217	436					
5 %									
10 %		170	266	332					
20 %		189	378	397					
30 %		217	391	627					
40 %		229	606	655					
50 %		256	617	671					
60 %		282	632	693					
70 %		306	646	716					
80 %		330	671	740					
90 %		553	506	767					
95 %									
Final boiling point, °F									
Pour point, °F									
Flashpoint, °F									
Viscosity at °F									
at °F									
at °F									
Asph. wt %					25.3				
Asph. melt temperature, °F					13.6	unreacted ash			
Heat of combustion, Btu/lb									
Carbon residue									
Carbon reduction, wt %									
Thermal stability									
Electrical conductivity									
Water									
Sediment									
Neutraliz.									
Corrosion									
Hydrocarbon type:									
Saturates									
Olefins									
Aromatics, total									
Aromatics, polynuclear									
Laminometer number									
Aniline point, °F									
H/C atom ratio									
Elemental analysis, wt %:									
C		86.4	88.0	89.6					
H		12.4	11.2	10.4					
N		0.067	0.044	0.008					
S		0.26	0.17	0.17					
O		0.07	0.058	0.08					
Trace metal analysis, ppm:									
V									
Ni									
Na									
K									
Mg									
Ca									
Pb									
Cu									
Fe									
B									
Zn									
Sn									
Mn									
Mo									
Co									
Pt									

(4) 3-femal turtles from Illinois #4 small (*Testudo terranovae*); data from same lot removed by John S. Clark, Wild Life Research Center, July 28, 1977.

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Property	Ton	Shortliss categories	
		Hydraulic underflow (F3200-87)	Hydraulic underflow filter (F3200-153)
Grain, °API (specific)		-16.3 (1, 2307)	17.7 (1, 2433)
Boiling range:	0-1100		
Initial boiling point, °F		666	693
5 %		573	598
10 %		506	567
20 %		415	471
30 %		390	400
40 %		370	397
50 %		376	392
60 %			310
70 %			
80 %			
90 %			
Final boiling point, °F			
Pour point, °F (softening point)		172	266
Flashpoint, °F			
Viscosity at 250°F, cP		207.5	161.6
at 300°F, cP			134.1
at °F			
Ash, wt %			
Ash melt temperature, °F			
Heat of combustion, Btu/lb			
Carbon residue (Gonradon), wt %		39.43	37.7
Carbon residue, wt %			
Thermal stability			
Electrical conductivity			
Water			
Solubility			
Reactivity			
Corrosion			

[illegible]

TABLE 6. - Continued.

(F) B-Coal fuel oil made, from Illinois #6 coal; data from ref. 6

Property	Test	Distillate categories ^a				
		Total overhead	<203°C(397°F); 35.6 percent	>203°C(397°F); 63.7 percent		
Gravity, °API specific		19.0 (0.935)	12.3 (0.864)	13.0(0.979)		
Boiling range						
Initial boiling point, °F						
5 %	ERDA	144	144	397		
10 %	Refluxing method					
20 %						
30 %						
40 %						
60 %						
80 %						
90 %						
95 %		627	397	627		
Final boiling point, °F						
Pour point, °F		-5	-5	-5		
Flashpoint, °F						
Viscosity at: 77°F., SUS		38				
at 100°F., SUS		35 (2.4cS)		39 (3.8cS)		
at 100°F., cS	D-445		1.06	3.87		
Ash, wt %						
Ash melt temperature, °F						
Heat of combustion, Btu/lb						
Carbon residue (Conrason), wt %	324	0.8	0	2.33		
Carbon residue, wt %						
Thermal stability						
Electrical conductivity						
Water						
Sediment						
Neutraliz.						
Corrosion						
Hydrocarbon type:						
Paraffins		19.56	33.9	12.0		
Olefins		2.1	5.9			
Aromatics, total		52.94	34.2	78.0		
Aromatics, polynuclear		25.98	Trace	46.2		
Luminometer number						
Aniline point, °F						
H/C atom ratio						
Elemental analyses, wt %:						
C						
H						
N	Kjeldahl	0.44	0.42	0.446		
S	D-129	0.21	0.13	0.29		
O						
Trace metal analyses, ppm:						
V						
Ni						
Na						
K						
Mg						
Ca						
Pb						
Cu						
Fe						
Si						
Zn						
Ba						
Mn						
Mo						
Se						
Pt						

^aDistillate, 37.9 percent of crude.

TABLE 6. - Continued.

(g) D-Cmal synarude made, from Illinois #6 coal; data from ref. 6

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Property	Test	Distillate categories ^b				
		Total overhead	<157°C(317°F); 35.6 wt%	>157°C(317°F); 85.3 wt%		
Gravity, °API (specific)		17.0(0.955)	34.7(0.838)	6.6(1.025)		
Boiling range:						
Initial boiling point, °F		138	138	387		
5 %	IRDA					
10 %	routine					
20 %	method					
30 %						
40 %						
50 %						
60 %						
70 %						
80 %						
90 %		795				
95 %						
Final boiling point, °F			387	795		
Pour point, °F		+5	+5	+5		
Flashpoint, °F						
Viscosity at 77°F, SUS		59				
at 100°F, SUS		46		77		
at 100°F, cS	D-445	6.1	0.96	14.6		
Ash, wt %						
Ash melt temperature, °F						
Heat of combustion, Btu/lb						
Carbon residue (Conradson), wt %		2.3				
Carbon ramification, wt %						
Thermal stability						
Electrical conductivity						
Water						
Sediment						
Neutrality						
Corrosion						
Hydrocarbon type:						
Paraffins		19.44	42.6	7.4		
Olefins		1.24	3.6			
Aromatics, total		51.13	31.4	80.9		
Aromatics, polynuclear		32.57	Trace	64.8		
Laminometer number						
Amaline point, °F						
H/C atom ratio						
Elemental analyses, wt %:						
C						
H						
N						
S	Ejeldahl	0.633	0.212	0.871		
O	D-124	0.27	0.06	0.35		
Trace metal analyses, ppm:						
V						
Ni						
Na						
K						
Mg						
Ca						
Pb						
Cd						
Fe						
Mn						
Zn						
Al						
Ba						
Mo						
Si						
Cu						

^bDistillates, 48.2 percent of crude.

(b) 8-Oml cycrode made, from Illinois 66 anal; data from ref. 7

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Property	Test	Distillate categories						
		Total crude	180° - 380°F	380° - 650°F	650° - 975°F			
Gravity, °API (specific)		6.6	30.6	14.0	-2.3			
Boiling range:								
Initial boiling point, °F		180	180	372	639			
5 %			226	420	652			
10 %			248	440	670			
20 %			264	474	728			
30 %			280	500	737			
40 %			292	510	754			
50 %			306	520	799			
60 %			318	542	823			
70 %			330	568	840			
80 %			338	593	868			
90 %			364	616	932			
95 %			386	670	969			
Final boiling point, °F		975	445	680	975			
Pour point, °F		-5		-100	86			
Flashpoint, °F								
Viscosity at 100°F, SUS		707 (155 cS)		41 (4.4 cS)				
at 210°F, SUS				36 (2.7 cS)	163 (36 cS)			
at °F								
Ash, wt %		0.03						
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramolition, wt %					4.4			
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								
Hydrocarbon type:								
Saturates								
Olefins								
Aromatics, total, percent (Asphaltene)		12.92		3.07	2.62			
Aromatics, polynuclear								
Luminometer number								
Aniline point, °F			86					
H/C atom ratio								
Elemental analysis, wt %:								
C		88.3	83.6	88.3	90.0			
H		8.19	12.41	9.73	7.58			
N		0.81	0.19	0.42	1.01			
S		0.22	0.24	0.18	0.22			
O		1.35	0.26	0.94	1.20			
Trace metal analysis, ppm:								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
B								
Zr								
Ba								
Al								
Mn								
Co								
Ti								
Refractive index			1.469	1.524	1.526			

(1) B-Coal; data from ref. 8

B-57

Property	Test	Distillate categories					
		Sample J-8088	950°F+ cut	950°F+ cut			
Gravity, °API (specific)							
Boiling range:							
Initial boiling point, °F		482		750			
1 %							
10 %		565					
50 %		620					
70 %		667					
80 %		705					
90 %		759					
95 %		866					
98 %		963					
99 %							
99.5 %							
99.9 %							
Final boiling point, °F			950				
Pour point, °F		-11					
Flashpoint, °F		32					
Viscosity at 21 °F, cS		316.7					
at 100 °F							
at 200 °F							
Ash, wt %	D-482	0.02					
Ash melt temperature, °F							
Heat of combustion, Btu/lb		17,411					
Carbon residue (Gordon), wt %		17.3					
Carbon residue, wt %							
Thermal stability							
Electrical conductivity							
Water							
Sulfur							
Acid number							
Acid value							
Corrosion							
Hydrocarbon type:							
Saturates							
Olefins							
Aromatics, total							
Aromatics, polynuclear							
Luminometer number							
Aniline point, °F							
H/C atom ratio							
Elemental analysis, wt %:							
C		89.0	90.33	87.52			
H		7.94	8.85	6.26			
N		0.77	0.99	1.39			
S		0.42	0.19	0.95			
O		2.12	0.53	3.56			
Trace metal analysis, ppm:							
V		3.0					
Ni		1.0					
Na		0.8					
K		0.4					
Mg		1.0					
Ca		8.0					
Pb		1.0					
Cu							
Fe		20.0					
Si		1.0					
Zn							
Ba							
Mn							
Mo							
W							
Ti		80.0					
Al		11.0					

(3) B-Coal hydrocarbon bottom filtrates; data from same for received by Theodore S. Hron, NASA Lewis Research Center, Feb. 26, 1976^c

Property	Test	Distillate categories				
		Illinois Geologic Institute	General Electric	Hastingshouse	AFAPL	BASA
Gravity, °API (specific)						
Boiling range:						
Initial boiling point, °F						
5 %						
10 %						
20 %						
30 %						
40 %						
50 %						
60 %						
70 %						
80 %						
90 %						
95 %						
Final boiling point, °F						
Pour point, °F						
Flashpoint, °F						
Viscosity at: °F						
at: °F						
at: °F						
Ash, wt %						
Ash melt temperature, °F						
Heat of combustion, Btu/lb						
Carbon residue						
Carbon ramabottom, wt %						
Thermal stability						
Electrical conductivity						
Water						
Sediment						
Neutrality						
Corrosion						

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Hydrocarbon type:							
Saturates							
Olefins							
Aromatics, total							
Aromatics, polynuclear							
Lumometer number							
Aniline point, °F							
H/C atom ratio							
Elemental analyses, wt %:							
C							
H							
N							
S							
O							
Trace metal analyses, ppm:							
V		Deut. A.	2-78v	At. abs.			
Ni		13 - 35	12.6		0.8	1.06	1.0
Na		18		9.08			10.0
K		2.7			1.2	10.08	
Mg		3.2	0.2		0.2	0.95	
Ca		3.8	4.3	1.84		2.4	2.0
Pb		1.48	2.7			0.61	
Cu				0.12	0.04		
Fe				3.06			2.0
B		12.1	4.7			35.8	8.0
Zn			5.0				2.0
Ba		1.5		0.67			
Mn		0.9					
Mo		1.8					
W		<0.7					
Al			2.0			2.0	

^cTotal of 52 trace elements listed in reference. Trace elements in filter cake also listed in reference.

(n) B-Coal distillate blends; data from ref. 39

Property	Test	Distillate categories					
		Sample 740-1117 (Fuel oil mode)	Sample 740-1121 (Syncrude mode)				
Gravity, °API (specific)							
Boiling range:							
Initial boiling point, °F		271	270				
5 %		322	328				
10 %		349	346				
30 %		372	367				
50 %		397	396				
60 %		412	405				
80 %		441	432				
90 %		467	454				
70 %		498	489				
80 %		540	530				
90 %		626	590				
95 %		697	662				
Final boiling point, °F		885	842				
Pour point, °F							
Flashpoint, °F							
Viscosity at at °F at °F							
Ash, wt %							
Ash melt temperature, °F							
Heat of combustion, Btu/lb							
Carbon residue							
Carbon residuum, wt %							
Thermal stability							
Electrical conductivity							
Water							
Sediment							
Acid number							
Corrosion							

Hydrocarbons (ppm):								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analyse point, °F								
H/C atom ratio								
Elemental analyses, wt %:								
C								
H		10.14	9.80					
N		0.34	0.38					
E		0.13	0.13					
O		1.70	1.50					
Trace metal analyses, ppm:								
V		0.3	0.3					
Ni								
Na		0.6						
K		0.7						
Mg								
Ca		0.7						
Pb		4.7						
Cu								
Fe		40.0	37.3					
Si								
Zr								
Ba								
Mn								
Mo								
W								
-Ti								

(a) B-Coal Burning Star (fuel oil mode); data from ref. 34

[illegible]

TABLE 6. - Continued.

(a) B-Coal Burning Star and Wyodak (syncrude made); data from ref. 39

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Property	Test	Distillate categories					
		Wyodak atmosphere overhead (760-1033)	Burning Star atmosphere overhead (760-3019)	Burning Star atmosphere bottoms (760-2031/3021)			
Gravity, °API (spec10c)							
Boiling range:							
Initial boiling point, °F		61	71	273			
1 %		162	159	420			
10 %		177	192	440			
20 %		211	231	470			
30 %		249	300	494			
40 %		288	322	518			
50 %		328	361	533			
60 %		358	381	563			
70 %		394	402	588			
80 %		428	432	634			
90 %		468	489	678			
95 %		499	507	722			
Final boiling point, °F		582	608	890			
Pour point, °F							
Flashpoint, °F							
Viscosity at °F							
at °F							
at °F							
Ash, wt %							
Ash: melt temperature, °F							
Heat of combustion, Btu/lb							
Carbon residue							
Carbon rammbottom, wt %							
Thermal stability							
Electrical conductivity							
Water							
Sediment							
Neutrality							
Corrosion							
Hydrocarbon type:							
Saturates							
Olefins							
Aromatics, total							
Aromatics, polynuclear							
Luminometer number							
Aniline point, °F							
H C atom ratio							
Elemental analysis, wt %:							
C		88.01					
H		11.85	11.37	8.86			
N		0.12	0.44	0.81			
S		0.09	0.24				
O		0.90	1.40	1.10			
Trace metal analyses, ppm:							
V							
Ni							
Ka							
K							
Mg							
Ca							
Pb							
Cu							
Fe							
Si							
Zn							
Ba							
Mn							
Mo							
W							
Ti							

TABLE 6. - FUEL DATA FROM SOLVENT-REFINED COAL PROCESS

(a) SEC products from Kentucky high-sulfur bituminous coals; data from vol. 18

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Property	Test	Distillate categories						
		Solvent-refined coal	Light oil	Heavy solvent	Process solvent			
Gravity, °API specific								
Boiling range:								
Initial boiling point, °F								
1 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at								
at								
at								
Asph. wt %								
Asph. melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon combustion, wt %								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Acidity								
Corrosion								
Hydrocarbon type:								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Aniline point, °F								
H/C atom ratio								
Elemental analyses, wt %:								
C								
H								
N								
S								
O								
Trace metal analyses, ppm:		RAA	SEP					
V								
Ni		4.0	2.1					
Na		8.8			1.7			
K								
Mg								
Ca								
Pb			41.0					
Cu			0.6					
Fe		270	300		160/-1			
Zn		8.1	7.1		0.580/-0.04			
Ba								
Mn								
Mo								
W								
As								
Cr		7.5	8.0		0.044/-0.006			
Al		2.3	1.8		0.0013/-0.001			

*Some analysis of hydrocarbon type listing ppm of individual constituents, but not in a manner that can be used to provide numbers in this table.

TABLE 6. - Continued.

(b) HEC products from Illinois 60 unit; data from ref. 19

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Property	Test	Distillate categories							
		92 HD-1	92 HD-2	93 HD-1	93 HD-2				
Gravity, °API (specific)									
Boiling range:									
Initial boiling point, °F									
5 %									
10 %									
20 %									
30 %									
40 %									
50 %									
60 %									
70 %									
80 %									
90 %									
95 %									
Final boiling point, °F									
Pour point, °F									
Flashpoint, °F									
Viscosity at °F									
at °F									
at °F									
Wt. wt %		0.19	0.31	0.19	0.25				
Ash: melt temperature, °F (SEC melt temp.)		312	367	327	356				
Heat of combustion, Btu/lb (unrec.)		15719	15733	15852	15623				
Carbon residue									
Carbon remainder, wt %									
Thermal stability									
Electrical conductivity									
Water									
Sediment									
Neutraliz									
Acid value									
Hydrocarbon type:									
Saturated									
Olefine									
Aromatic, total									
Aromatic, polynuclear									
Luminometer number									
Ignition point, °F									
H/C atom ratio									
Elemental analyses, wt %:									
C		87.12	87.48	86.67	86.38				
H		6.36	6.12	5.62	5.65				
N		1.87	1.89	1.91	1.95				
S		1.07	0.88	1.10	1.09				
O		3.19	3.32	4.36	4.97				
Trace metal analyses, ppm:									
V									
Ni									
Na									
K									
Mg									
Ca									
Pb									
Cu									
Fe									
Si									
Zn									
Ba									
Mn									
Mo									
W									

Considerable data on streams throughout the oiler plant. However, it is not apparent which are product output streams and which are internal streams only, other than the HEC products contained on this sheet.

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TABLE 2. - Continued.

(d) SEC (filtered and upgraded); data from ref. 1

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Property	Test	Distillate categories					
		Filtered SEC ^a	SEC filtrate ^b	Upgraded SEC ^c			
Gravity, °API (specific)		-3.8 (1.1237)	2.5 (1.0560)	9.6 (1.0020)			
Boiling range:							
Initial boiling point, °F		400	385	432			
5 %		520	428	555			
10 %		530	435	600			
20 %		585	450	660			
30 %		620	462	718			
40 %		652	475	780			
50 %		685	488	850			
60 %		740	535	940			
70 %		825	600	1000 at 652			
80 %		1020	700				
90 %			875 at 895				
95 %							
Final boiling point, °F							
Pour point, °F		50		55			
Flashpoint, °F							
Viscosity at 100°F, cP		864 (1900 cS)					
at 210°F, cS		20.45		72.99			
at 250°F, cS				14.43			
ash, wt %			0.02	0.001			
ash melt temperature, °F							
Heat of combustion, Btu/lb							
Carbon residue (Conradson), wt %				16.21			
Carbon ramolition, wt %							
Thermal stability							
Electrical conductivity							
Water							
Sediment							
Acidity							
Corrosion							

Hydrocarbon type:							
Paraffin							
Olefin							
Aromatic, total				91.7			
Aromatic, polynuclear							
Luminometer number							
Aniline point, °F							
H/C atom ratio							
Elemental analysis, wt %:							
C		86.77		90.81			
H		6.90		9.76			
N		1.28		0.508			
S		0.72		0.02			
O		3.81		0.02			
Trace metal analysis, ppm:							
V							
Ni							
Na		0.08					
K							
Mg		0.4					
Ca		0.5					
Pb							
Cu							
Fe		1.8					
B		8.8					
Zn							
Ba							
Mo							
Mn							
W							
Ti							
Al							

^aSpecifying 65 percent process solvent (3296-10 p. 37).^bAs received (3296-05 p. 66).^c3296-04 p. 79.

TABLE 8. - Conclusions.

(a) HEC (light organic liquid and viscous solvent)

Property	Test	Distillate categories				
		Light organic liquid (J-7951)	Acrylic solvent (J-7950)			
Gravity, °API (specific)		--- (1.02)	--- (1.03)			
Boiling range:						
Initial boiling point, °F		101	126			
5 %						
10 %		106	106			
20 %		125	109			
30 %		135	134			
40 %		148	154			
50 %		165	192			
60 %		175	128			
70 %		187	166			
80 %		407	195			
90 %		415	657			
95 %						
Final boiling point, °F		161	177			
Pour point, °F		55	45			
Flashpoint, °F		92	103			
Viscosity at 100°F, cS		1.661	1.88			
at 210°F, cS		0.667	1.666			
at °F						
Ash, wt %	D-402	18.	3.			
Ash: melt temperature, °F						
Heat of combustion, Btu/lb		17 226	16 715			
Carbon residue (Conradson), wt %		0.01	0.08			
Carbon residue, wt %						
Thermal stability						
Electrical conductivity						
Water						
Substance, wt %		0.07	0			
Residue						
Corrosion						

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Hydrocarbon type:						
Saturated						
Olefins						
Aromatic, total						
Aromatic, polynuclear						
Luminometer number						
Acidic point, °F						
H C atom ratio						
Elemental analysis, wt %:						
C		86.72	87.34			
H		7.98	7.56			
N		0.23	0.59			
S		0.40	0.32			
O		3.60	4.05			
Trace metal analysis, ppm:						
V		0.0	0			
Ni		1.7	0.2			
Na		1.9	1.6			
K		0.4	0.4			
Mg		0.1	0.2			
Ca		0.5	0.4			
Pb		0.9	0.3			
Cu						
Fe		17.9	4.4			
B		0	0			
Zn						
Se						
Mo						
Mn						
P						
Si		11.8	11.9			
As		0.4	1.5			

(F) HSE produced from Kentucky #9 coal; data from Letter of May 16, 1973, to T. V. Reynolds, Bala Lewis Research Center, from Robert G. Speth, Pittsburgh & Midway Coal Mining Co.

Property	Test	Distillate composition					
		Solvent- refined oil	Raw solvent	Light- oil			
Gravity, °API specific			— (0.986)	— (0.934)			
Boiling range:	B-55						
Initial boiling point, °F			383	155			
1 %			403	219			
10 %			409	289			
30 %			413	318			
50 %			417	322			
60 %			421	332			
70 %			425	343			
80 %			430	359			
90 %			436	357			
95 %			444	366			
99 %			455	389			
99.5 %			463	400			
Final boiling point, °F			482	402			
Pour point, °F; fusion point, °F		430					
Flashpoint, °F							
Viscosity at 77°F, cS				1.226			
at 100°F, cS			2.75	9.794			
at °F							
Ash, wt %		0.3					
Ash: melt temperature, °F							
Heat of combustion, Btu/lb							
Carbon residue							
Carbon remanescence, wt %							
Thermal stability							
Electrical conductivity							
Water							
Sediment							
Neutralizy							
Corrosion							

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TABLE 8. -- Continued.

(a) HEC (light organic liquids and various solvents); data from ref. 39

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Property	Test	Distillate categories						
		Light organic liquids (740-1291)	Acyclic solvent (740-1019)	Acyclic solvent (740-1289)	Acyclic solvent (740-1290)			
Gravity, $^{\circ}\text{API}$ (specific)	g	— (0.8470)	— (1.0318)	— (1.0333)	— (1.0333)			
Boiling range:								
Initial boiling point, $^{\circ}\text{F}$		83	321	306	326			
5 %		169	261	273	267			
10 %		177	275	293	290			
20 %		213	400	409	403			
30 %		250	416	434	441			
40 %		284	443	453	470			
50 %		317	468	483	501			
60 %		339	498	510	550			
70 %		347	537	551	586			
80 %		384	586	594	661			
90 %		399	647	669	771			
98 %		420	688	724	859			
Final boiling point, $^{\circ}\text{F}$		543	864	902	1007			
Pour point, $^{\circ}\text{F}$								
Flashpoint, $^{\circ}\text{F}$		18		180	182			
Viscosity at 100 $^{\circ}\text{F}$, cS			5.56	5.78	10.66			
at 210 $^{\circ}\text{F}$, cS			1.45	1.48	2.25			
at $^{\circ}\text{F}$								
Ash, mg/g , ppm	D-482		10	100	100			
wt: melt temperature, $^{\circ}\text{F}$								
Heat of combustion, Btu/lb		18 158	18 826	16 921				
Carbon residue (Conradson), wt %			0.29	0.19	0.22			
Carbon residue, wt %								
Thermal stability								
Electrical conductivity								
Water		0		0	0			
Sediment								
Neutrality								
Corrosion								
Hydrocarbon type:								
Saturated								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Leak-tightness number								
Analysis unit, $^{\circ}\text{F}$								
H:C atom ratio								
Elemental analysis, wt %:								
C		83.70	88.00	88.40				
H		11.33	7.65	7.43	8.78			
N		0.30	0.38	0.42	0.50			
S		0.60	0.51	0.37	0.35			
O		4.09	4.09	3.90	3.38			
Trace metal analysis, ppm:								
V		9.2	0.2	0.9	4.0			
Mn		8	0.2	0	0			
Ka		0.4	0.3	0.4	0.4			
K		0.3	0.3	0.2	0.2			
Mg		0	0	0	0			
Ca		0.1	15.0	0.4	0.5			
Pb		7.4	4.0	0	0.9			
Cu								
Fe		2.1	13.0	11.8	54.0			
Si		0	0	1.0	0			
Zn								
Ba								
Mo								
Nb								
W								
Ti		10.2	9.6	20.0	0			
Al		0	1.0	4.0	0			

(b) SEC (Wilsonville Process Solvent); data from ref. 39

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Property	Test	Distillate composition			
		Process solvent (768-1189)	J-4511	J-4511	J-4513
Gravity, °API specific		5.3	13.6	19.5	23.4
Boiling range					
Initial boiling point, °F	B-1007	334	173	180	172
5 %		375	303	216	207
10 %		394	352	260	232
20 %					
30 %		446	413	402	387
40 %					
50 %		492	469	463	432
60 %					
70 %		564	534	525	495
80 %					
90 %		645	627	602	578
95 %		709	681	649	630
Final boiling point, °F		872	857	818	814
Pour point, °F					
Flashpoint, °F		180	87	48	62
Viscosity at 100 °F, cS		5.79	3.43	2.20	2.00
at 210 °F, cS		1.48	1.10	0.93	0.90
at °F					
Ash, wt %					
Ash: melt temperature, °F					
Heat of combustion, Btu/lb		16921	17728	18572	18903
Carbon residue					
Carbon ramification, wt %					
Thermal stability					
Electrical conductivity					
Water					
Sulfur					
Humidity					
Corrosion					

Hydrocarbon type:					
Saturated					
Olefins					
Aromatics, total Carbon 1	74	56	44	34	
Aromatics, polynuclear					
Luminometer number					
Aniline point, °F					
H/C atom ratio					
Elemental analysis, wt %:					
C					
H	7.43	8.88	10.32	10.99	
N	0.62	0.44	0.11	0.07	
S	0.37	0.08	0.01	0.01	
O	3.90	2.40	0.60	0.20	
Trace metal analysis, ppm:					
V	0.9	<0.1	0.1	<0.1	
Ni					
Na	0.39	1.1	0.08	0.05	
K	0.19	0.22	0.03	0.01	
Mg					
Ca	0.35	0.23	0.12	0.12	
Pb	0.9	0.9	0.6	0.3	
Cu					
Fe	61.0	2.3	1.5	3.4	
Mn					
Zn					
Ba					
Mo					
W					
Ti	20.0	1.0	1.0	1.0	

(Data from ref. 28.)

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Property	Test	Distillate categories						
		Heavy naphtha		Fuel oil				
		Raw liquid	Hydrotreated liquid	Raw liquid	Hydrotreated liquid			
Gravity, ρ_{40} (specific)		(0.87)	(0.80)	(1.08)	(1.01)			
Boiling range:	Residual	158 - 392	158 - 392	392 - 1000	392 - 1000			
Initial boiling point, °F								
1 %								
10 %		223	198	477	462			
20 %	15/5							
30 %	Distillation							
40 %	D-2892							
50 %		356	315	694	657			
60 %								
70 %								
80 %								
90 %		790	760	811	774			
96 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt %								
Ash: melt temperature, °F								
Heat of combustion, Btu/lb	Fisher	18300	18300	17100	18100			
Carbon residue								
Carbon rambottom, wt %								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Controlity								
Corrosion								

Hydrocarbon type:								
Saturated								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Amine point, °F								
H/C atom ratio								
Elemental analysis, wt %:								
C		85.60	86.80	89.40	90.80			
H		10.92	12.90	7.70	8.60			
N		0.21	0.06	0.66	0.24			
S		0.47	0.005	0.41	0.04			
O		2.82	0.23	1.83	0.32			
Trace metal analysis, ppm:								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Mn								
Zn								
Be								
Mu								
Mo								
W								
Li								